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Economic Operation of Micro Grid Considering Electric Vehicle Storage System

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ABSTRACT

Abstract in italiano

Con la crescente consumazione delle fonti dell'energia tradizionale, il peggioramento dell'inquinamento ambientale, ed graduali incrementi dei requisiti della qualità di energia elettrica dai clienti, la tecnologia di generazione distribuita ed energia pulita basata sull'energia rinnovabile è stata utilizzata ampiamente in rete energetica. La smart grid, come una efficiente forma per la generazione distribuita ad accedere alla rete energetica, è un sistema flessibile, controllabile e autonomo che redistribuisce l'energia elettrica, lo stoccaggio e surplus di energia tramite il controllo di potenza e la gestione del sistema energetico. Inoltre, considerando la crescente importanza e l'enorme potenziale dei veicoli elettrici, l'azione della smart grid insieme alla stazione energetica dello stoccaggio di energia per veicoli elettrici indica gradualmente la strada per la soluzione dei peggiorati problemi energetici e ambientali e delle integrazioni di qualità dell'energia. In conseguenza, come ottimizzare la smart drid contenuta la stazione energetica dello stoccaggio di energia per veicoli elettrici e i vari tipi di generazione distribuita, la qual'è fortemente influenzata dalla configurazione dello stoccaggio è un argomento importante.

Questa tesi presenta una breve introduzione in primo luogo, poi analizza la relativamente matura usata generazione distribuita fotovoltaica, turbina eolica, micro turbina, e batteria. Il capitolo due studia le loro caratteristiche di output, il principio di generazione dell'energia elettrica, le caratteristiche del funzionamento e la relazione tra i parametri di funzionamento e l'economia stabilendo i modelli economici delle micro-grid unità secondo le curve di output costo.

Basando sulle caratteristiche della cella e di intervento di veicoli elettrici derivate dai relativi dati, stabilisce e costruisce un modello matematico della stazione energetica dello stoccaggio di energia per veicoli elettrici, ed utilizza un esempio applicando i veicoli elettrici alla programmazione cooperativa per ottimizzare la curva di surlpus di energia. Tenendo conto dell'impatto di configurazione capacità dello stoccaggio di energia, dopo di aver stimato e programmato in Matlab la durata della batteria usando l'algoritmo di rain flow, converte l'investimento dello stoccaggio di energia in un costo quotidiano che viene elencato nella funzione obiettiva.

Dopo la completazione dei modelli economici di ogni elemento, la tesi divide i veicoli elettrici coinvolti in smart grid in tre livelli: carico normale, carico spostato e V2G rispedisce a rete energetica. Inoltre la smart grid è gestita con due metodi: unità ottimazzazione e due-stadi ottimazzazione. I modelli sono stabiliti tramite tre modi: isole energetiche, rete energetica connessa, rete energetica connessa alla potenza di scambio costante. Elencando le funzioni obiettive e le condizioni corripondenti ad ogni modo di funzionamento, tali funzioni verranno stabilite e programmate in CPLEX.

La potenza sbilanciata a dovuto della perdità di carico e turbina eolica/fotovoltaica verrà considerata nel modello introducendo una punizione rappresentata da un coefficiente di rigore. Tale termine permette di migliorare l'utilizzo di energia rinnovabile e convertire il carico con bassa efficienza di utilizzo e basse prestazioni del costo nel costo del rischio dal punto di vista economico.

Infine, è presentato un caso di una zona industriale dotata della stazione energetica dello stoccaggio di energia per veicoli elettrici. In seguito della valorizzazione dei propri parametri, il centro di gestione dell'energia è in grado di elaborare e gestire l'output di differenti generazioni distribuite e riportare il risultato al controllore di smart grid. Sotto la circostanza della richiesta di carico e la costrizione integrale di output, il costo totale è minimizzato. Riferito al risultato, per la causa della mancanza della fornitura da grande grid applicando le isole energetiche, la quota del costo è relativamente elevata. L'investimento in eccesso è dovuto alla tendenza della richiesta riguardo lo stoccaggio di energia. Come il dispacciamento dell'energia coordinato, veicoli elettrici consentono di regolare la curva di carico e uscita micro-fonte effettivamente e ulteriormente approfittare dello sparso tempo di batteria rimandando l'energia elettrica alla rete energetica. Il coefficiente di rigore è sensibile al parametro e relativamente piccolo, che coincide col caso reale.

Parola chiave: smart grid; veicoli elettrici; economia; ottimizzazione; rete energetica connessa; isole energetiche.

Abstract in inglese

With the growing consumption of traditional energy sources, increasing environmental pollution and gradually improvement of power quality requirements of the customs, distributed generation and clean energy technology based on renewable energy, have been widely applied in the grid. As an effective form for distribution generation to access into the grid, micro grid is a flexible, controllable autonomous systems organized by distributed power, energy storage and load by power control and energy management. Coupled with the increasing importance and the enormous potential of electric vehicles, the micro grid operation including energy storage power station of electric vehicles is gradually pointing out a direction for the worsened energy issues, environmental issues and the integration of power quality solution. How to optimize the micro grid containing electric vehicle storage station which is heavily influenced by storage configuration is an important issue to economical optimization operating.

This thesis will firstly give a brief introduction and then analyze the relatively maturely used distribution generation photovoltaic, wind turbine, micro turbine and battery. Chapter 2 will analyze their output characteristics, power generation principles, operating characteristics and establish economic models for these micro grid unit according to their output cost curves.

Then, according to relevant data, thesis will derive cell characteristics and trip characteristics of electric vehicles, build and construct a mathematical model and use an example by applying electric cars into cooperative scheduling to optimize load curve. Taking into account the impact of energy storage capacity configuration, after calculating and programming in the MATLAB by rain flow algorithm lifetime estimation, the investment of energy storage after converting into daily cost is listed in the objective function.

After that, the thesis will divide the depth of electric vehicle involving into the micro grid into three degrees: as normal load, as shifting load and V2G sending back to grid. Two methods of two-step optimization and unified optimization will be used to calculate the optimization from three modes, that is, isolated island, grid connected and grid connected with a constant exchange power. Models of different operation will be built and programed in CPLEX.

The unbalanced power of load shedding and wind turbine/photovoltaic will be considered in the model by introducing a penalty item, which is the penalty represented by the penalty coefficient. The brought in of this item will improve the utilization efficiency of renewable energy and convert the load which has a low utilization efficiency and cost performance into risk cost from the economic point of view.

The study case about an industrial district will be given in the last part of the thesis. After calculating the model with proper parameters, the energy management center can work out and arrange the output of different distribution generation and send the result to the Micro grid controller. Under the circumstance of load demand and all the output constraints, the total cost is minimized. According to the result, because of the lack of supply from big grid when isolated island operation, the operation fee is high relatively speaking. The extra cost is spending on the storage system. As the coordinate dispatching element, electric vehicle can smooth the load curve and random source output effectively and even make a profit by sending power back to the grid in the spare time of the battery. Penalty cost is sensetive to the parameter and relatively small, which is coincide with the reality.

KEYWORDS: Micro grid; Electric vehicle;Economic; Optimization; Grid-connected; Isolate island

1 INTRODUCTION

1.1 Background and Significance of the Study

1.1.1 Background of the Study

Energy is the foundation of human existence and development. Through series of use from development to sustainable initiatives, mankind achieves continuous economic growth and social development. However, with the development of the society, excessive usage of coal and other fossil fuel are exploited to generate electricity so that the depletion of resources and deterioration of the environment becomes a serious challenge. With the continuous expansion of the grid size, the drawback of ultra-large-scale power system has become increasingly prominent: high cost of operation, difficult to adapt to the increasingly requirements of users such as high security and reliability as well as a variety of power supply mode. Meanwhile, with the rising of oil prices, energy supply continue tense worldwide, the rational development and utilization of green energy has become an important issue, while the development of clean and efficient use of renewable energy is the main solution to solve the energy problems[1]. Continued demand for energy, the environment needs to be protected, the large power supply system has its own potential problems, it is in this context that distributed generation (DG), as one way to solve the problem, have been proposed in order to make full use of renewable energy as well as improving the energy supply structure.

Distributed generation refers generally to a relatively small power generation device arranged in the user's site or nearby. Renewable energy has less pollution, high reliability, high energy efficiency, flexible installation location and many other advantages. It is an effective solution to many potential problems of large centralized power grid. Microgrid is defined as a small generation and distribution system whcih contains the distributed power, energy storage, energy conversion devices, and monitoring and protection device and load[2]. It achieves the controlling and management by two operation modes of isolated island operation and parallel operation. It uses a lot of modern power technology to collect wind power, photovoltaic power generation, gas turbines, fuel cells, energy storage equipment, etc together and directly connected to the user side[3-5]. For large power grids, the microgrid can be regarded as a controllable unit, which can achieve the requirement of the state of the transmission network through rapid action outside; from the perspective of users, the microgrid can meet their specific requirements such as increasing local reliability, reducing feeder loss and providing uninterruptible power supply and other needs.

With the increase ownership of cars, the dependence on oil consumption is also growing. The promotion and use of electric vehicles is in favor of pressure relief. As shown in some data[6], to many countried, oil depends on import, if electric vehicles can be use in a large area, the demand for oil imports will be reduced by 30% to 40%. Take US power grid for example, if the electric car market share reaches 20%, the charging power of these electric vehicle consumption will count for 2% of the total electricity demand.

1.1.2 Significance and Value of the Study

EV Energy supply facilities are an important part of electric car industry chain, which can be divided into decentralized charging station and centralized swap station[7]. Decentralised charging electric vehicle charges through the distribution of a cell or in the vicinity of residential charging pile, using small power to charge slowly. While battery swap station provides the service to replace the empty battery block, and then collect the empty batteries and charge at the appropriate time, through an orderly way at the right time and the right place for charging. However, large-scale EV access will result in grid, such as: electricity peak load increasing, widening the difference between peak valley difference of the load, the carrying capacity of the output power and the impact on the power quality, introducing harmonic and a series of influence. In order to solve these above problem, scholars launched a series of studies, in which the electric vehicle access to micro grid is a direction that can be considered.

Microgrid contains a variety of distributed power, some power such as: wind, light, etc. are just random power affected by natural resources, some distributed power such as micro gas turbine, etc., can be regarded as a controllable power which has the characteristics of renewable power, intermittent, easily influenced by the environment, a higher initial investment costs and maybe the output capacity of both heat and electricity simultaneously[8]. After the EV accessing to the microgrid, it can be operated in the mode of plug-in and swap. In the daytime, load is greater than the supply, so the power grid support it. At night the system take full use of wind energy and other new energy to charge the battery, increasing the utilization of wind energy as well as peak valley shifting and smoothing the curve. In summary, a reasonable choice of the type of micro grid generator and the operation and economic analysis is very important, especially the micro grid system including wind turbine, photovoltaic and storage unit. The rational configuration and economic operation of the micro grid is premise to build real microgrid and providing a theoretical reference for the planning and construction of the micro grid. The ability to withstand disturbance of micro grid comparing with traditional power system is relatively weak, particularly wind power, solar power and other distributed energy which has a strong randomness. The system faces higher risk, so the effective and economic dispatching of micro grid is an important part to be studied.

In most cases, economic analysis is based on micro grid installation costs, operation and maintenance costs as well as the auxiliary equipment aims at satisfying the reliability demand, power quality and pollutant emissions control costs. From the current study, economic analysis technology of micro grid is mainly reflected in the following aspects:

1) The investment and operational optimization of micro grid. According to local information, in the condition of meeting the user-side heat, cold, electrical load demand, power quality standards, the main network specific requirements and demand-side management requirements, determine the micro grid distributed generation system operating mode according to the best principles of economic efficiency.
2) Evaluate and quantify the economic of micro grid. Investment and operational optimization of microgrid can directly be seen as the performance evaluation of economic benefits. But it has yet to find an effective way to express the micro grid benefit users, the electricity department and the community in a reasonable and quantified way. With the deepening of the research and development of micro-network, how to quantify the economics of micro grid will become an important research topic.
3) New economic characteristics of the micor grid. A considerable difference between the micro grid and traditional power grid is the distributed generation units, power electronics control devices and energy storage elements change the network structure and flow characteristics of the distribution network, so that the microgrid planning needs not only to meet network planning requirements, but also consider some characteristics of micro network itself, which makes micro-network planning have some new economic characteristics.

Micro grid economy including electric vehicles energy storage power station has its unique characteristics. Compared with the traditional centralized energy supply systems, distributed energy supply systems is generally placed in the load area and has several ways of energy use, such as solar, wind power, gas turbines, fuel cells and electric car batteries. And the transfer process is relatively short with a smaller loss. Secondly, the distributed power generation system can be flexibly adjusted according to the load of each power generation unit, and there is not too much regional constraints, which makes it can be installed anywhere. These features make the economic operation of microgrids need to study its distributed power output characteristics, such as the gas turbine cogeneration mode, output of photovoltaic and wind conditions, the battery charge and discharge characteristics.

Researches on the micro grid worldwide mainly concentrates on the grid connecting, protection and communication technology, planning and design, operation control and energy management and other works. But the economic dispatching of distributed power was not studied enough. The cleaning use and environmental benefits have not yet been fully reflected. With the development and maturity of micro grid technology, the micro grid economic dispatching considering the requirement of electric car accessing to the grid becomes more and more important. Therefore, in order to promote the application of micro grid in power system, the studies of micro grid economic operating has become an important issue.

1.2 Reasearch Status

1.2.1 Concept of Micro Grid

Micro grid is a power supply system composed of load and micro generator, which provide energy as well as providing quantity of heat. Micro grid internal power primarily achieve regulation of energy conversion and systems control through power electronics. Microgrid is seen as a single controllable with unit respect to the external power grid, which will meet the requirement of power quality and user’s security requirements. Micro grid is mainly divided into micro grid contains the DC bus systems, micro grid system with AC bus and micro grid contains a mixture of AC and DC bus.

Distributed generation is a small electricity generating device near the user’s end. Its form is diverse, it can be PV, gas turbines. Micro source convert different forms of energy into electricity and converge to a common connection point at the PCC through a power electronic device.

Micro grid energy storage unit is a necessary part to ensure electricity reliability and energy power balance. When the microgrid load demand and distributed power generation capacity do not match, the cell provides the necessary buffer for the entire system through absorbing and emiting energy. The presence of micro grid energy storage unit allows to adapt to load fluctuations better as well as various types of failure, greatly improve the reliability of the microgrid.

The switch of micro grid between stand-alone and grid-connected operation by controlling the micro grid and power grid interconnecting switch to achieve. Interconnected switches also typically include some measurements and control units, which is used to determine switching time to ensure the switching operation to meet the relevant regulatory requirements (mainly the voltage, frequency and phase of both sides switch, etc.).

Microgrid as a controllable element, makes the appropriate action as large grid needed, also needs the help of control auxiliary systems. The controller determines not only operation state of microgrid, but the mode of independent operation or parallel operation, and by adjusting the output voltage and frequency of the grid at each state to ensure the stability of the grid.

Micro grid topology structural shown in Figure 1-1 presents that micro grid connected with the external distribution network through disconnecting switch. Compared to large power grids, micro grid can be regarded as a stand-alone system, or an controllable unit which can meet the demand of external distribution network. The power output amount of different DG is determined by the energy management control, which will select the appropriate control method to adjust according to the system operating status. In addition, the power flow controller can also adjust the power flow in the limited range of energy management equipment to assist the control of micro grid.

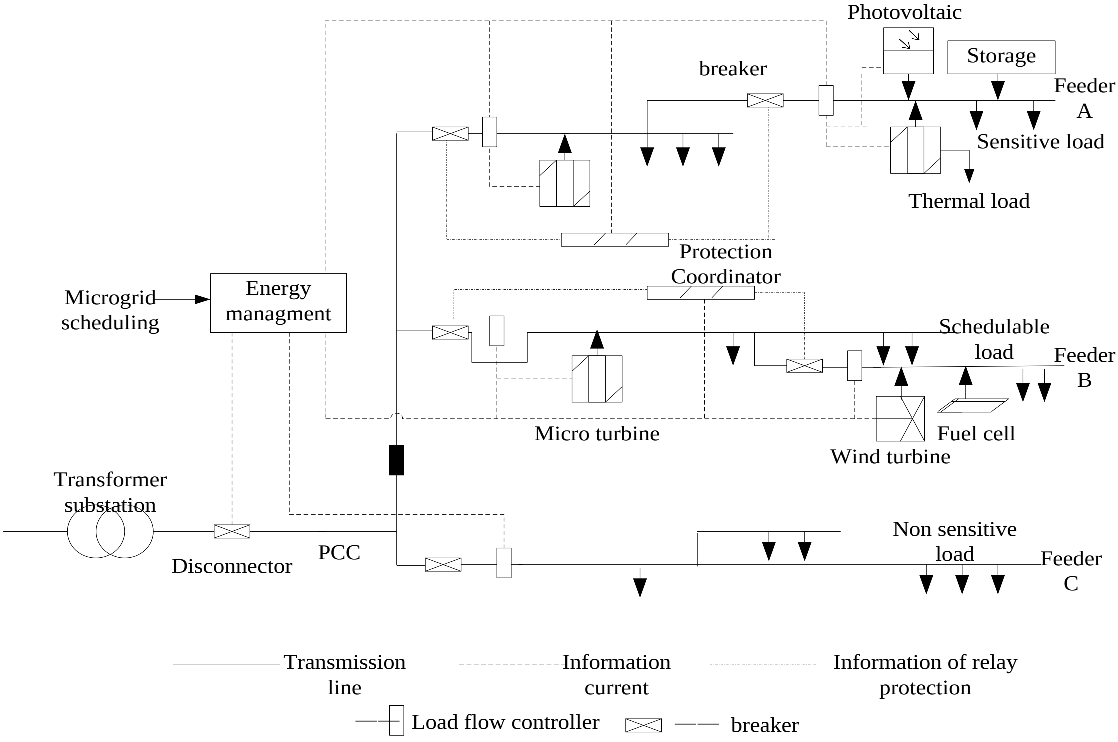

Figure 1-1 Structure topologyof Micro grid

Micro network comprises a plurality of distributed power (photovoltaic, wind turbine) and distributed energy storage devices. It can be connected to the system via power electronic devices and joint supply power to the load. This micro-network has three radial feeder (feeder voltage can be adjusted according to the actual situation). As shown in the figure, the feeder A can achieve thermal and electrical double cogeneration. The normal power supply of the sensitive load can be insured by the local power supply and energy storage devices. Feeder C is connected to the non-sensitive loads, in some special cases may waive the load and cut off the feeder as the requirements of energy management.

When the micro grid and power grid are interconnected, MG can draw energy from the power grid. Distributed power output can adjust the output according to the load change on their own, together to ensure the needs of micro-power network load. When a fault occurs and an iaolated island state is in need to operate. MG will disconnected from the power grid, taking use of micro-power source to support the important short-term load. If the voltage, frequency, etc. can not meet the requirements, the load carried by the feeder B will be adjusted to ensure the supply of sensitive loads. The state to recover from isolated grid to gird connected requires only to close the breaker. Microgrid achieve the conversion between different operating conditions in this way, as a backup power to ensure the stable and reliable of power supply.

Microgrid shown above is just one of its structure, but it embodies the basic characteristics of the micro-network, including distributed power supply (single-supply capacity of about 1 ~ 100 kW), relay protection, distributed storage, key unit equipment,such as load and so on. Micro grid has autonomy, as long as the properly control, which can be seen as an element of the grid. When the capacity of the micro-network within the distributed power and distributed energy storage device is large enough, it can postpone the construction of transmission and distribution upgrades as well as saving money. This particular form of micro grid makes up many problems of large power grid, making full use of distributed generation technology while ensuring the supply of some important load and improve the reliability of power supply.

1.2.2 Reasearch Status at Home and Abroad

Currently, the microgrid research work have been carried out in many countries. According to their power system characteristics and national development goals, different countries make their own micro grid development strategies.

US CERTS (Consortium for Electric Reliability Technology Solutions) proposed microgrid concept early in the world. The microgrid raised by CERTS, mainly composed by the distributed power, energy storage systems and corresponding load. Through energy conversion device, primarily the role of the converter, it can achieve easily "plug and play." With the introduction of micro grid, the main purpose is to improve the reliability of supply for critical loads, to meet the demand of users as well as reducing grid manufacturing costs, and ultimately the goal of building the smart grid.

Micro grid of Europe focused on electricity demand, energy security of supply and environmental protection. They proposed "Smart Grid" plan and technology strategy in 2005 and 2006. For microgrid operation, control, protection, security and communications technology, Europe has achieved numbers of research results and these theoretical results were verified through experimental demonstration[9]. Its main task subsequently is to study the control strategy and application of standards, and try to operate through the establishment of demonstration project to prepare for the popularization and development of micro grid.

Research and development of micro grid also received widespread attention in recent years in many aspects of society in China. The government wants to use the micro grid technologies to explore new ways of operating and management for the development of distributed renewable energy. The state grid company wants to build micro grid demonstration project to solve the operation and management problems led by numbers of distributed power network. Manufacturing companies want to get the new business opportunities for manufacturing by the build of micro gird. Some of the energy management companies and power suppliers want to explore self-organization and self-management by taking advantage of micro grid and universities and research institutions also hope to study micro grid technology to explore new theories and methods. Big natinal project like 863,973(Chinese national project code) have been promoted for the contribution to the theoretical research and demonstration projects in this area. Research and Construction of microgrid in Chian has made some achievements, a number of new micro grid demonstration projects have been built, and will continue to advance in the future[10-11].

Japan also launched many micro grid research. To expand the scope of micro power supply, microgrid concept in Japan list the small power generation systems that take use of traditional energy in micro source.The aim of developing micro grid of Japan lies in that by introducing a diversification energy supply system, to ease the energy supply crisis, reducing fossil fuel pollution of the environment and meet the diverse demand of users for the power supply[12]. Meanwhile, Japanese scholars also proposed the concept of friends-flexible reliability and intelligent electrical energy delivery system and by the use of Flexible Alternative Current Transmission Systems(FACTS), the charactiristics of fast devices and flexible features to optimize the energy structure of distribution network.

1.2.3 Operation and Control of Micro Grid

The operation of micro grid need firstly to build models for varieties of power generations, heating power, energy storage element and controller. The modelling includes mathematical model which compose the system unit, the stochastic output model of renewable energy unit, energy storage discharging control unit and capacity recognition models. While renewable energy output forecast is one of the very important aspects. Accurate prediction of photovoltaic, wind power with long-term or short-term generation capacity, are the basis of micro grid system rational planning and also key points of micro grid operating[13-14]. Some foreign research organizations made certain achievements about the relevant micro grid operation such as that EU makes meticulously research division for centralized control and decentralized control of micro grid system respectively; Japan has developed a corresponding energy management software and applied it to an actual project. In China, research on micro grid study focused on wind power, photovoltaic and energy storage units such as batteries, super capacitor, flywheel energy storage system. In recent years, energy management research also made progress.

There is a difference between Micro grid operation mode, electricity market and energy policy with a conventional power system. When the micro grid is in the grid-connected operation state, it can exchange energy with the external grid. One situation is that micro grid takes use of distributed power to meet the internal load demand as possible. It can absorb energy from the main network, but not give energy back to the main network. The other case is to allow the micro grid to participate in the open electricity markets. Allowing the free exchange of energy between micro grid and the main network, in this way, not only the distributed generation but also the demand side can take part in the auction. When the micro grid is in the mode of isolated operation, the ability to undertake disturbances is relatively weak. Then by the effective control and management of storage system, it can stabilize fluctuations in renewable energy and load fluctuations in demand for maintenance the system, among which plays an important role in the stable operation.

Because of the presence of distributed generations, control mode of micro grid is not exactly the same as the control in conventional power systems. As a result, it requires the coordination of distributed generation units and the development of micro grid system level control and management software, such as short term and ultra short term load forecasting and renewable energy output forecast, unit commitment, dispatch management and system monitoring. The US CERTS has proposed the user side model of distributed power and is now developing micro grid analysis software. US GE company and Japan's micro grid demonstration project are also working on micro grid energy management, in order to develop the management software collecting the function of protection, control and energy management of micro grid together. Microgrid control system generally consists of three levels. First is the level of electricity distribution network and market. Through the control of micro grid area to achieve the main grid and distribution network scheduling capabilities. Second is the control of micro source and energy storage element, mainly for micro source and energy storage grid connected inverter control, including a variety of control strategies like PQ, Vf and droop control and so on; Finally it is microgrid level control, namely the different control mode based on different combinations of micro sources control[15], to achieve the stabilization operations through regulation of system voltage and frequency, including master-slave control, peer to peer control and agents hierarchical control.

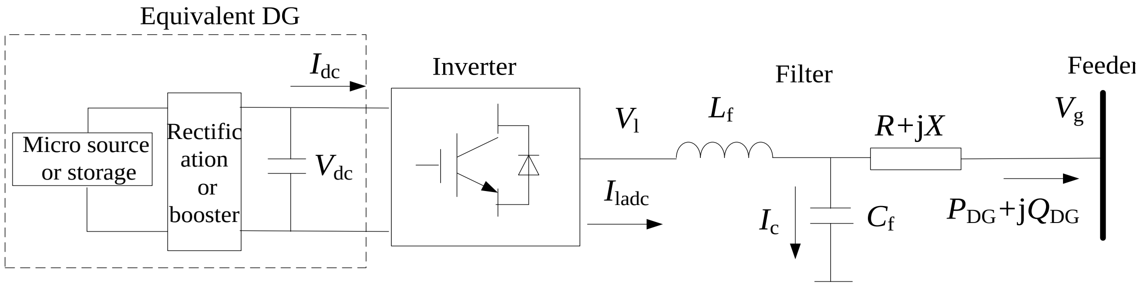

Figure 1-2 the grid connected figure of distributed generation

In summary, the operation control and management strategies of micro grid can be decided by combining local thermoelectric demand, electricity price, fuel costs, power quality requirements and demand-side management and so on, in order to achieve the following basic functions: supply the power and volatge set point for the unit controller of distribution generation and ensure that it meets the demand of the load side; ensuring micro grid to meet the operational requirements of the main grid, which will make the least operating costs and system costs, so that the distributed power gets the maximum operating efficiency.

1.2.4 Development Status of Electrical Vehicle

With the increasingly prominent energy, environment problems, the research and development pace of electric vehicles is accelerating, and the input quantity is also gradually increasing. Compared with conventional vehicles, in terms of reducing fuel consumption, electric vehicles have an absolute advantage over other technologies. Other technologies promise to reduce gasoline consumption 41-56% per vehicle, while electric vehicles can reduce fuel consumption by 100% [16]. If 30% of the total number of cars in China in 2030 is electric car, it will save 700 million barrels of oil, which not only reduces the depletion of primary energy concerns, but can also charge the car during night so as to improve equipment utilization. In addition, the use of electric vehicles will greatly improve air quality and reduce greenhouse effect, control temperature increasing, sea level rise and other environmental issues. Electric cars have a higher initial purchase cost, but the usage cost is lower, according to the relevant measure [17]: take the BYD electric vehicles as an example, the power consumption is only 57kWh/300km, equivalent to the price of less than 60 RMB(China's currency). Calculate by the fuel vehicles to 10 l/km with prices of 7 RMB/liter, driving 300km needs around 230 RMB. When taking into account the price differences in peak periods, the price for electric vehicles will be much lower, saving more than 70%. In the long term, along with the adjustment of the cost of petrol price and technology improvement bringing down the price of electric cars, the electric cars may become the choice for ordinary consumers for the sake of affordable purchase.

Because of the above advantages, the electric car has been vigorously promoted by Governments. The United States, Japan, Europe invested largely in the development of electric cars and the charging equipment, charging stations and other infrastructures of electric vehicles, as means of economic development. The Chinese government has also taken some actions to initiate the development and use of electric vehicles. Since 2001, the government issued several energy saving, environmental protection and security regulations and policies, and new energy vehicles have also been included in the "863" project Program of the "Eleventh Five-Year", "Twelfth Five-Year", including electric vehicles [18].

However, the cycling charging of the electric cars will lead to the following problems to the power grid [19]: 1) Because electric car users tend to have similar behavior, when the electric cars connect to the grid at the same time, it will occupy grid reserved capacity, reducing the anti-risk ability of the grid and bringing hidden dangers of the stable operation of the grid. If not rule the charging mode, it will increase the peak load of electricity, enlarge the peak-valley gap of grid, and challenging the load bearing ability of the power system; 2) Connecting electric vehicles to the grid will cause the power losses increasing, harmonic pollution and some other issues, thereby reducing power quality and affecting the safe operation or service life of other electrical equipment and devices.

In addition, it is necessary to study the electric vehicles dispatching methods. The economical dispatching strategy highlights the economic indicators, coordinated dispatching, reducing the loss as the goal upon the united control of the distributed energy of the region, including electric vehicles. And make the electric car users or operators adjust their charging and discharging behaviors by themselves in order to save costs and even profit, through the market mechanism and level-price, as an indirect method.

The research of electric vehicles connecting to the grid has also achieved some progress: reference [20] studied the impact of electric vehicle charging on the grid, and analyzed charging characteristics of the batteries and the user behaviors, established load model for the charging of users, according to the US survey data. Reference [21] based on the statistical data , presented the statistical model of the power demand and validated the increase of the grid power load caused by the charging characteristics by simulation. Reference [22] studied V2G (Vehicle to Grid, V2G), and developed the model with electric vehicle model involved in dispatching by the use of certain optimization algorithm, and made it smooths the peak-valley of the load by the use of objective functions. Reference [23] analyzed the mathematical model of electric vehicles and wind power cooperative dispatching, to smooth load fluctuations and absorb the excess wind power, by the use of electric cars charging during night. Reference [24] started from the generator costs and environmental issues, and solved the assembly problems of the generators by the use of mixed integer programming methods. Reference [25] is based on the economic aspect: it discussed the economics in terms of the fixed investment of the energy storage, operating costs of the micro grid and expenses of electric vehicle owners, etc. and it also proposed a specific numerical example. Reference [26] took IEEE 118 bus system as an example, it built a joint operation of electric vehicles and micro grid. Reference [27] established a multi-time scale wind power-electric car model, and analyzed the load shifting and specific measures for the inhibition of wind overflow, based on the measured data of Northwest and North China Power Grid. Reference [28] analyzed the electric vehicle accessing from the time and space point of view, and proposed a set of program from addressing to optimized dispatching.

The research on this subject is still in the exploratory stage, and has a large innovation potential. The process of electric vehicles accessing to micro grid, has a significant meaning either in theory or practice, through the realizing by independently control of the micro grid towards the distributed network or the introduction of flexible charging and discharging of electric vehicles according to the market mechanisms. It’s also very important for the promotion of electric cars and the incoming problem solving.

1.3 Contents and Scenario

This thesis build the unit economic model for all the elements in the system by analyzing the basic characteristics and operating characteristics of micro grid including electric vehicle.

According to three ways of electric vehicle's participating in the dispatching of micro grid, the EV participation is divided into three ways: random charging, shifting charging and V2G sending back to the big grid. To analyze the operation, there are also three operation modes: isolated grid, grid connected and grid connected with a constant exchange power, which means there is a contract between the micro grid and distribution grid so that a constant exchange power is consumed all the time. According to different strategies, objective functions and constraints are listed, considering converting the investment cost of battery into daily cost. In the total cost, we introduce the risk cost which represents the load shedding and renewable power overflow. By programming in CPLEX and calculating the optimum according to different strategies, the best economic scheduling result is achieved.

Figure 1-3 shows the frame and structure of this thesis.

Specific content are includes in the following sections:

1）Describe the background and significance of the topic, including basic knowledge, research status and operation characteristics of micro grid, etc.

2）Analyzing the relatively mature distributed generation like wind turbine, photovoltaic, micro turbine and battery, study their output characteristics, power generation principles, operating characteristics and the relationships between operating parameters and economy, etc.

3）Electric vehicle battery characteristics and trip characteristics were studied. The thesis use rainflow algorithm to estimate the battery lifetime and program in MATLAB to estimate. According to related information of TESLA electric vehicle, chapter 3 estimate the cost for a one-time storage. After getting one-time cost and lifetime, it can be converted to a daily cost which is coordinate with our time period. According to the US Department of Transportation data, the charging expectation in 24 hours is calculated. So the mathematical model of electric vehicle energy storage station is built and one case example is studied by applicating the electric cars cooperative scheduling to optimize load curve.

4）According to the output and operation characteristics of different elements in the micro grid, the unit economic models of wind turbine, photovoltaic, micro turbine and battery are defined. Considering the storage investment cost, micro source operation cost, risk cost and power exchange cost, objective function and constraint are listed to build a micro grid system economic model under different strategies and situation.

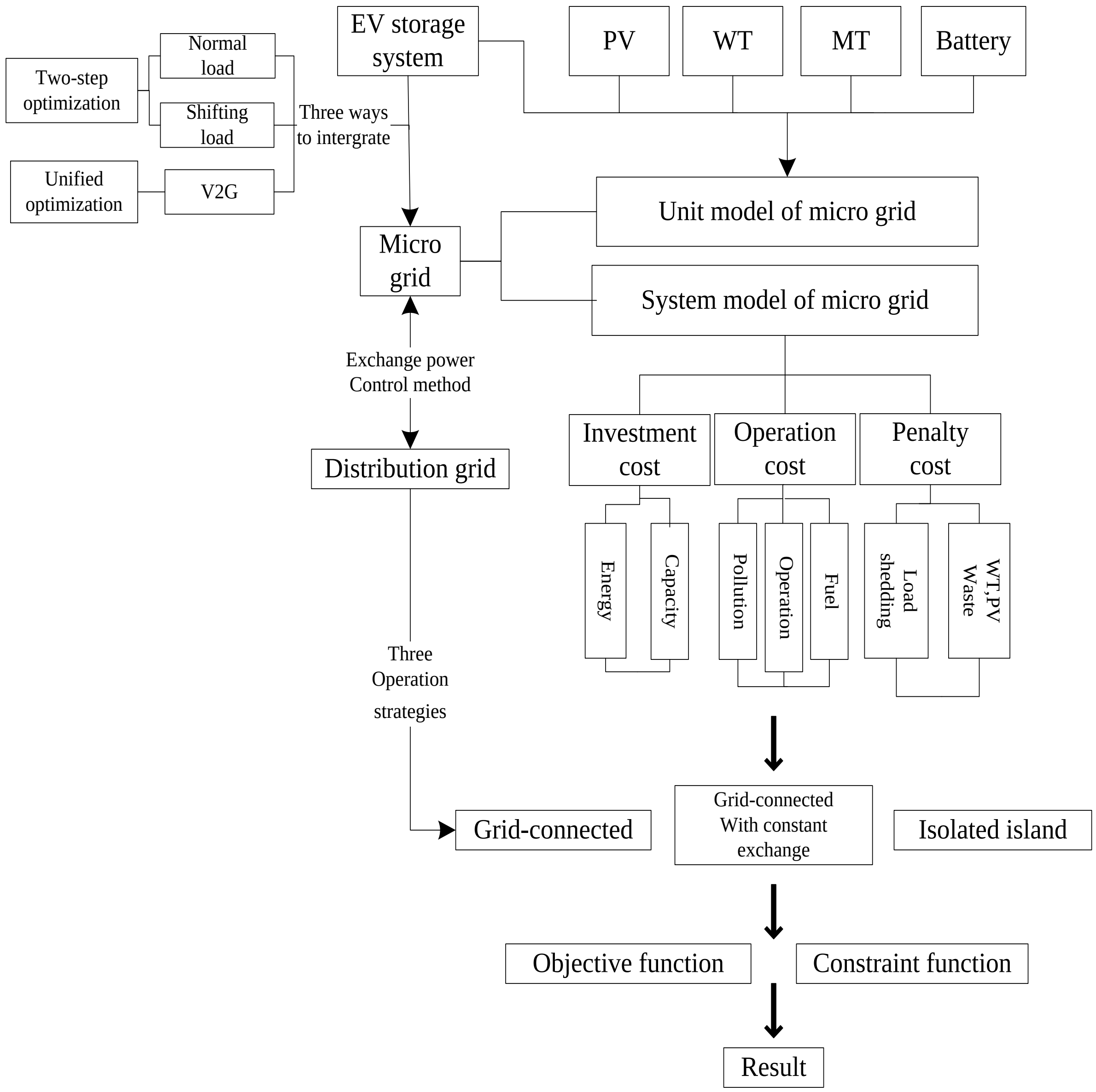

Figure 1-3 The frame and structure of the thesis

5）Analysis of the way of intergrating mode of electric vehicles into micro grid operating patterns. By comparing the different points of isolated island mode, grid connected mode and grid connected with constant exchange power mode, the different situation of electric vehicle involved in the micro grid is classified in two categories: electric vehicle work as charging load and electric vehicle participating in the scheduling. The latter mode can be divided in turn into: electric vehicle serving as shifting load just transferring the charging time and making use of the battery inside EV to be dispatched. Two ways of step optimization and unit optimization are considered to solve the result respectively.

6）A case of industrial district is studied. The micro grid in the industrial district contains a solar photovoltaic, wind turbine, microturbines, batteries, electric vehicles storage station and electrical load. By setting the parameters of all the unit and adopting the daily load and weather in Autumn in a city in northern China, we get the initial value. After programming in CPLEX and calculating, the specifics solution for all variables in different situation are computed. Some conclusions are achieved which can be proved also by theoretic identification.

2 THE ANALYSIS OF DISTRIBUTION GENERATION

2.1 Photovoltaic (PV)

In PV systems the component to achieve energy conversion from solar power to electric power is called photovoltaic cell, also known as solar cell, which is the basic unit of photovoltaic power generation system. The PV cells are encapsulated into a solar cell module, by series-parallel solar cells, which is further assembled into solar arrays (PV Array) by a series-parallel connected.

Solar cell is the minimum power gerneration unit, and the voltage of each piece is about 0.5V. In order to achieve the desired voltage and capacity requirements, it should be series and parallel connected to form a solar cell module. If the battery voltage is 12V, the PV module needs 36 solar cells. Actually, it’s usually 36 or 40 cells, and high-power components may be higher.

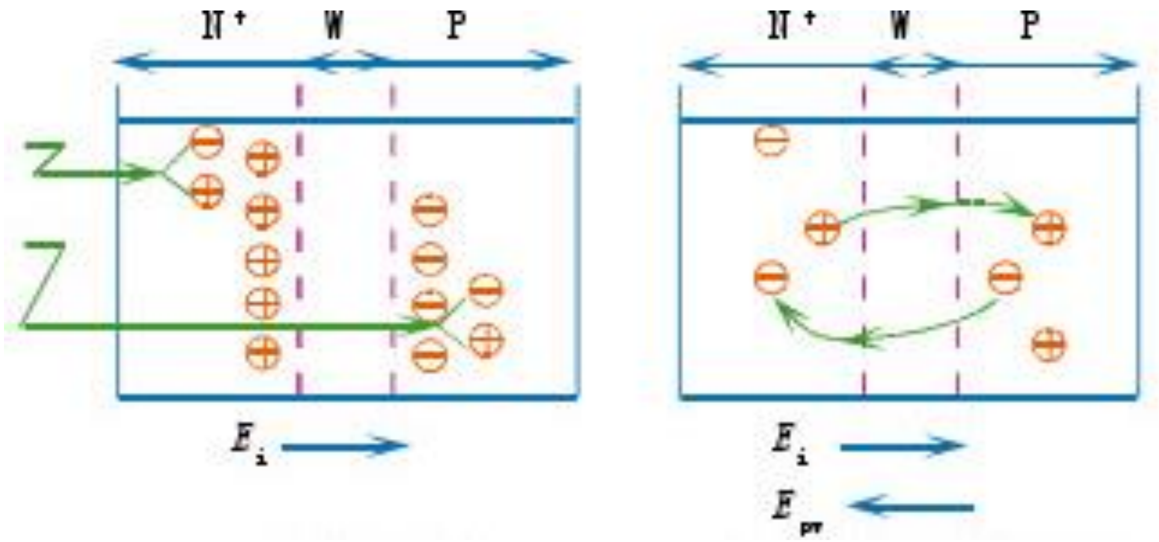

Figure 2-1 Principle of photovoltaic (forming photon injection and photo-electric field)

Photovoltaic cells generate power by the photoelectric effect while the light incidences on the semiconductor. Figure 2-1 indicates the principle of photovoltaic mechanisiom, which can be explained with the PN junction. Since the majority carriers diffuses to the other side of the PN junction, a very narrow charge region formed, which establishes the self-built electric field *E*, but there exists traction for the minority carriers on both sides[29]. When photons incident on the semiconductor, the photons produce electrons and holes in semiconductor material, while the electron accepts solar power, spreading to the N-type semiconductor, so the N-type semiconductor is negatively charged; meanwhile, the holes move to the P-type conductor, so that the P-type semiconductor is positively charged, which produce electromotive force between the PN junction. When a wire is weilded on the electrode of P-type and N-type semiconducter, and turn on the load, the conducting path is formed.

So after getting the model of photovoltaic cell, the model for photovoltaic array can be obtained by series-parallel connecting the unit model. The PV model mainly discusses the basic UI model of photovoltaic cell, simplified engineering model and the model considering the avalanche effect and so on. Photovoltaic-based equivalent circuit is shown in Figure 2-2 [30]:

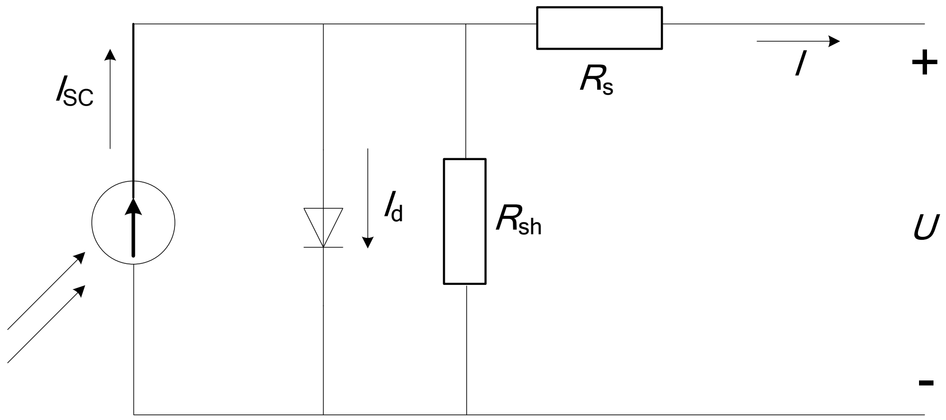

Figure 2-2 The equivalent circuit of the photovoltaic cell

Its U-I characteristics are:

$$I = I_{ph} - I_d[e^{\frac{q(U+IR_s)}{AkT}} - 1] - \frac{U+IR_s}{R_{sh}} \tag{2.1}$$

Where the diode represents the characteristic of PN junction; R_s and R_{sh} are the equivalent of series and parallel impedance; T is the cell temperature; q is the electron charge; A is a dimensionless fitting constants, between 1 and 2, when the PV outputs high voltage, A=1; when its low voltage output, a = 2; k is the Boltzmann's constant; I_{ph} and I_d are photocurrent and reverse saturation drain current flowing through the diode, and these two quantities are environment dependently, and the light intensity and temperature should be considered, the calculation formula is as follows:

$$I_{ph} = I_{sco}[1 + h_t(T - T_{ref})]S / S_{ref} \tag{2.2}$$

$$I_d = b_1 T^3 \exp(-a_1 / T) \tag{2.3}$$

Where: I_{sco} stands for the short circuit current of standard sunshine and temperature; the temperature coefficient h_t = 6.4 × 10-4K^{-1}; T is the temperature of the photovoltaic cells; T_{ref} is the standard battery temperature; constant a_1 = 1.336, b_1 = 235; S is light strength; S_{ref} is the standard light intensity.

A typical photovoltaic system is devided intoindependent photovoltaic and power generation systems and grid-connected photovoltaic power generation system, including PV array, inverter, controller, while for the former one, there usually exsits a battery. Two types of photovoltaic system is shown in Figure 2-3.

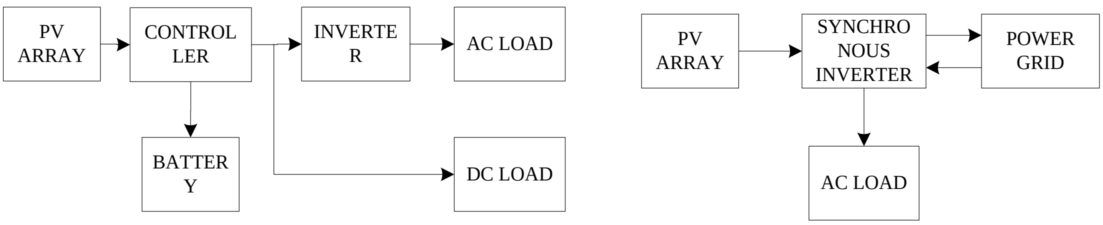

Figure 2-3 Independent photovoltaic power generation systems and grid-connected photovoltaic power generation system

The function of the solar photovoltaic arrays is to achieve solar-to-electricity conversion, outputing low DC voltage. Typically, converter comprises a DC-DC converter and DC-AC inverter, which changes the less stable DC power into high-quality AC current. Wherein the controller performs the sampling, monitoring of the PV array and battery status, and generates a control signal for the inverter according to the set of algorithms. For independent photovoltaic systems, battery stores energy when the photovoltaic cells output is under adequate conditions, and in the case of insufficient power output of photovoltaic cells, it will supply energy [31].

PV power is some kind of natural resources, the power generation costs can be considered to be zero.

2.2 Wind Power

Since the decreasing of coal, oil and other non raw dwindling natural resources, worldwide as well as coal, oil combustion environment pollution and other reasons, the world has turned to the low-carbon renewable energy sources research, development and utilization . For low-carbon energy development and utilization of the fastest growing and most technologically sophisticated undoubtedly is the wind power technology.

In China, wind power resource is abundant, and the potential exploitation amound of the wind power in the height of 50 m above the ground and above level 3 is about 2.38 billion kW. With the utilization of large-scale wind power in China, it achieved a high development rate. By the end of 2009, the total installed capacity of wind power reached 26 million kW or more, and the total has been ranked second in the world. Given its good prospects for development, national planning objectives have been further enhanced to 150 million kW in 2020. Then wind power will become the third largest conventional energy after thermal, hydro power in China at that time.

In order to improve the power generation efficiency and economic benefits, research of modern wind power systems trends to large-scale and shifting pitch direction. VSCF power generation is a new power generation technology developed from the 1970s gradually, which applied the vector control technology, power electronics technology and computer control technology into the motor-control applications, showing the good operating characteristics, and have gradually replaced fixed speed traditional constant frequency wind power technology,becoming the world's widely used technology.

VSCF technology makes wind turbine speed as the wind speed changes, and constant-frequency electrical energy can obtained through other control strategy, who has the characteristic of varing the speed of the motor over a wide range without affecting the frequency of output power. This variable speed wind turbine can be utilized to the maximum extent so as to improve efficiency. In addition, the fan, the stress on the fan is steady, the acceleration and deceleration of the wind wheel produce buffer action for the step changes of wind energy, improve the operation stability and security of the wind turbine, reduce operating noise, achieve a good flexible connection between the generator and the grid system, with excellent operating characteristics and design performance. In recent years, in domestic and foreign countries, the research focus of VSCF generator is mainly contain the direct drive permanent magnet synchronous generator, DFIG[32].

Wind power uses wind to generate electricity, by converting wind energy into mechanical energy, and then convert the mechanical energy to electrical energy, no conventional energy consumption, so the cost of electricity is only the maintenance costs and management costs only. Wind power investment costs includes wind power construction costs as well as wind power management and maintenance costs[33], wind power costs C_c are mainly the acquisition cost of the wind turbine (prices for shipping to the installation site) P_e, wind farm infrastructure costs E_i, wind turbine lifting commissioning costs C_d and wind power network construction costs E_n.

$$C_c = P_e + E_i + C_d + E_n Closs \; = \; COST * D \tag{2.4}$$

Investment in wind power projects is in longer term, usually 20--25 years, whose depreciation costs D_v should counts the time effect, calculated based on the pension as:

$$D_v = \frac{r(1+r)^n}{(1+r)^n - 1} C_c \tag{2.5}$$

Therefore, the cost of wind power is as follows：

$$C = (D_v + O + M) / W \tag{2.6}$$

Where O is the operating costs, including material costs, management fees, wages and welfare; M is for the annual maintenance fee; W for the annual generating capacity of wind turbines.

The main factors affecting the amount of wind generators are wind speed, wind turbine characteristics and the rotor shaft height.

The relationship between the fan output power and wind speed is:

$$W = \frac{1}{2} \rho A V^3 \eta \tag{2.7}$$

Where: W is the output power for the wind turbine; ρ is the wind energy density; A is rotor swept area; V is the wind speed; η is for the wind turbine power coefficient. Obviously, the output power of the turbine is propotional cubic of wind speed, the higher the wind speed is, the higher the power generation, and also the lower of unint electricity costs.

Measured wind speed data for a large number of statistical results shows that the random variation of wind speed can be described by a two-parameter Weibull distribution, whose distribution function is[34]:

$$F(v) = 1 - e^{-(\frac{v}{c})^k} \tag{2.8}$$

Where: k is the shape parameter; c is the scale parameter, m/s. Wind speed probability density function v is：

$$f(v) = (\frac{k}{c})(\frac{v}{c})^{k-1}\exp[-(\frac{v}{c})^k] \tag{2.9}$$

Without considering factors such as air density, a typical relationship between the output power of the wind turbine and wind speed is[35]：

$$P(v) = \begin{cases} 0 & 0 \le V < V_i \\ \eta(v)P_r & V_i \le V < V_r \\ P_r & V_r \le V < V_e \\ 0 & V > V_e \end{cases} \tag{2.10}$$

Where: $\eta(v)$ is a complex function related to the wind speed, which is a linear function：

$$\eta(v) = \frac{V - V_i}{V_r - V_i} \tag{2.11}$$

As can be seen from the above equation, when the wind speed is above the rated wind speed, wind turbine can reach the rated power.

The axle height of wind turbine will have some impact on the electricity generation. Under normal circumstances, when close to the ground, the wind speed increases with the increasing of the height, wind speed variation by height is calculated as follows:

$$\frac{V(z)}{V(z_0)} = \frac{z}{z_0} x \tag{2.12}$$

Where: $V(z)$ is the wind speed at height *z* from the ground. $V(z_0)$ is the wind speed at a height of z_0 from the ground; *x* is the conversion factor, usually taken as 1/7.

Obviously with increasing of the height of turbine axle, the wind speed increases, power output increases and the generation cost of wind power decreases.

2.3 Microturbine

In the 1990s, the advent of micro gas turbine have produced a sensation in the global distributed generation marke. With the support of the US Department of Energy and the European government, the Capstone Turbine Company of the United States, Allied Signal Inc. (later incorporated into Honeywell Inc.), Elliott companies and British company Bowman have joined the micro gas turbine bussiness.

Capstone Turbine Company in the mid-1990s pioneeredly pushed out the world's first micro gas turbine, while the capacity of single unit is 30kW, 60kW and subsequently launched 60kW and 65kW type. Then the Honeywell introduced the 75kW unit. Elliott introduced 100kW, Bowman introduced 80kW. For a time, microturbine came to flourish. After 2001, the United States IR company also joined this industry, and launched a 70kW and 250kW single machine. After 2004, Capstone Turbine has introduced a 200kW unit, and on this basis of this, 600kW, 800kW and 1MW modules have been launched with the integrated electrical, control and fuel systems. With the changes in the global economy as well as some of the company's changed their business strategy, some vendors closed its microturbine business, so far, the companies who remain of micro gas turbine business are mainly US Capstone Turbine company and Elliott company[36].

The structure of the micro gas turbine is simple, which usually uses the radial turbomachinery and single-stage centrifugal compressor, with pressure ratio typically 3-5; single-stage centripetal turbine, while the turbine and compressor is back to back whole wheel structure. The 50000-120000r/min high speed often uses air bearings, without run oil and lighter units, such as the Capstone C30 (30kW) engine is just 109kg, which weighs less than a 3kW diesel generator set.

Micro gas turbine has the following characteristics[37]：

1) It can use a variety kinds of fuels, like natural gas, kerosene, or even up to 7% sulfur-containing acid gas ratio.

2) Power generator is small size, light weight, and follows the principle of plug and play design, while the installation is simple, just entering the gas pipelines and output power line to work.

3) Lower operating noise, which is measured to be 65dB of 10m from the gas turbine.

4) Having a high energy conversion efficiency, when there is a regenerator, the thermal efficiency is up to 30%, and the CHP thermal efficiency can be increased to 80%.

5) Pollution is less. The oxy-fuel achieves the complete combustion, the particulate and soot emissions is almost zero, and nitrogen oxide emissions is very low, less than 9 ×10-6, making it the green power.

6) High reliability, low failure rate, long service time without maintainess. The first repair of the micro gas turbine is after 8000h working time generally, also with lower maintenance costs, and the general operating life is more than 45000h.

7) There are built-in automatic monitor operation system and remote control systems, which can achiebe a high degree of automation.

8) Residual heat energy can be utilized, which can generate power, heating and cooling jointly though the combination use of heat regenerator, absorption, steam or hot water air-conditioning system, so as to realise the cool-heat-electricily trigeneration and improve energy efficiency to more than 80%.

With the changes in demanding for the energy and power structures worldwide, and environmental protection requirements, some government departments attach great importance in the micro gas turbine, where the cool-heat-electricily trigeneration has achieved a rapid development. The United States has more than 60 regions of the cooling system, the installed capacity has reached 45000MW. In Japan, combined heat-power (CHP)system is the third largest public welfare after gas and electricity. In Europe, the CHP generating capacity accounts for 18% of its total generating capacity.

In the economyic operation of trigeneration system, the cooling and heat cost should be considered. Gas consumption of the micro gas turbine is[38]：

$$Q_1 = 3600 \times \frac{Q_f}{E} = \frac{3600}{\eta_e} \tag{2.13}$$

The residule heat in the flue gas waste is：

$$Q_2 = \left(1-\eta_e\right) Q_1 * \eta_y \tag{2.14}$$

Where: Q_f , E are the gas consumption and electricity generation of the micro gas turbine, respectivily; while η_e , η_y are for power generation efficiency and flue gas residule heat utilization of the micro gas turbine.

Apportioned the gas consumption to electricity generation：

$$Q_3 = Q_1 - Q_2 = \frac{3600}{\eta_e}[1-(1-\eta_e)\eta_y] \tag{2.15}$$

The unit cost of electricity generation can be drawn according to the following equation：

$$c_e = \frac{Q_3}{Q_f} \times c_f = \frac{3600 c_f}{Q_f * \eta_e}[1-(1-\eta_e)\eta_y] \tag{2.16}$$

$$c_e = \frac{Q_3}{Q_f} \times c_f = \frac{3600 c_f}{Q_f * \eta_e}[1-(1-\eta_e)\eta_y] \tag{2.17}$$

Where c_e is the electricity unit cost, RMB/kJ; Q_f is the low calorific value of natural gas, kJ/m^3; while c_f is the natural gas price, RMB/m^3.

2.4 Battery

Energy storage is very important to satisfy the basic functions of micro grid and to achieve economic benefit. The micro grid ask for the following requirements in energy storage[39]: 1) to ensure the quality of power supply, such as voltage compensation; 2) to guarantee reliability of power supply, such as an uninterruptible power supply; 3) to improve the grid connected performance of the new energy, such as stabilizing the intermittency of the output power of wind power and other new energy sources; 4) to improve energy efficiency. From the scale and characteristics of the micro grid, the techeniques which are suitable for micro grid technologies includes battery energy storage, super-capacitor energy storage, flywheel energy storage and superconducting magnetic energy storage.

As for the battery energy storage, there are a few important battery parameters, namely capacity *Q*, state of charge (State of Charge), depth of discharge (Depth of Disharge).

The output capacity of the battery is the product of the different discharge current and its duration.

$$Q = I_1 t_1 + I_2 t_2 + \cdots + I_n t_n = \sum_{k=1}^{n} I_k t_k = \int_0^t I dt \tag{2.18}$$

Where: $t_1 ... t_n$ are the discharge duration; $I_1 ... I_n$ are the discharge current of each time period, respectively.

The rated capacity of battery is, referring to a temperature of 20-25 degrees, with full-charged and being set aside for 24 hours, the output capacity of 10 hours discharge rate to the output voltage.

There are two important state parameters of battery, which are the state of charge SOC and the depth of discharge DOD, on behalf of the residual capacity and the percentage of release capacity of the total capacity of the battery.

$$SOC = \frac{Q_R}{Q_{Sum}} \tag{2.19}$$

$$DOD = \frac{Q}{Q_{Sum}} \tag{2.20}$$

Where: Q_R The residual battery capacity under this conditions, *Q* is the battery capacity been released. When the battery is full, SOC is 1, and DOD = 1-SOC.

Since the lead-acid battery is the need to consider the specific physical and chemical processes, the equivalent circuit model is usually used in the electrical engineering field, the following is a dynamic model of the battery model.

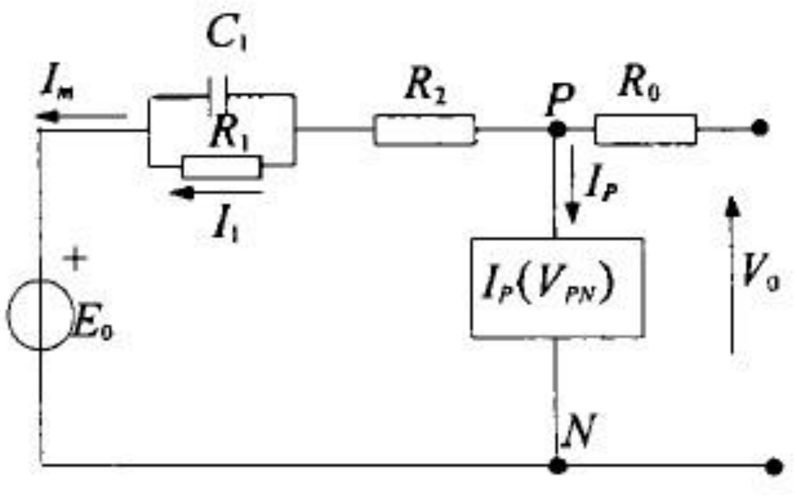

Figure 2-4 Third-order dynamic model battery

In Figure 2-4, the RC network, the voltage source are the main reaction branches; the main reaction branch considers the electrode reaction inside the battery, the energy distributing and ohmic effects. Parasitic branch mainly considered the gassing reaction during charging. The circuit consists of two RC network and a algebraic parasitic branch.

$$E_0 = E_{m0} - K_E(273+\theta)(1-SOC) \tag{2.21}$$

$$R_0 = R_{00}[1+A_0(1-SOC)] \tag{2.22}$$

$$R_1 = -R_{10}\ln(DOC) \tag{2.23}$$

$$R_2 = R_{20}\frac{\exp[A_{21}(1-SOC)]}{1+\exp(A_{22}I_m/I^*)} \tag{2.24}$$

$$C_1 = \tau_1 / R_1 \tag{2.25}$$

Among them, E_{m0}, K_E, R_{00}, A_0, A_{21}, A_{22} for a battery is constant. Where the SOC (state of charge), DOC (charged depth) are defined as:

$$SOC = 1 - Q_e / C(0,\theta) = 1 - Q_e / (K_c C(I^*)) \tag{2.26}$$

$$DOC = 1 - Q_e / C(I_{avg},\theta) \tag{2.27}$$

Where $Q_e = \int_0^t -I_m(\tau)d\tau$, I_{avg} is the average current, I^* is the reference current, θ is the electrolyte temperature, K_c is the experience factor, which is a constant:

$$C(I,\theta) = \frac{K_c C_{0*}(1-\frac{\theta}{\theta_f})^{\varepsilon}}{1+(K_c-1)(\frac{I}{I^*})^{\delta}} \quad (2.28)$$

Where I is the discharge current; θ_f is the electrolyte condensation temperature; C_{0*} is when electrolyte temperature of 0 degrees Celsius, the requiered discharge capacity under the reference current I^*, and it's a constant; δ , ε are experience constants.

The prediction of the battery capacity level is the important part in the battery energy management system. The battery capacity is affected by the aspects, such as: concentration of battery electrolyte, electrode materials, depth of discharge, internal resistance and other factors. Because the battery's residual capacity or state of charge can not be directly measured, it is deduced only through the external characteristics of the battery: voltage, current, resistance, temperature and other parameters, and these parameters change with the aging of the battery. So that in the prediction of the residual battery capacity, a variety of methods can be taken. Methods currently online test are the following: 1) the voltage detection discriminating; 2) the discharge current detection; 3) thee battery internal resistance prediction; 4) a combination of the integrated methods.

The following table is a comparison of performance of several storage methods[40].

Table 2-1 Comparative characteristics of several energy storage

Energy storage method	Output Power /MW	Discharge Duration	Response time	Cycle life / million times
Flywheel	0-0.25	1ms-15min	1ms-20ms	2
SMES	0.01-10	1ms-8s	1ms-5ms	10
Supercapacitor	0-0.1	1ms-1h	1ms-20ms	5
Lead-acid battery	0-50	m-h	＞20ms	1.2
Vanadium redox flow battery	0.03-3	s -10h	20ms-s	1.2
Sodium-sulfur battery	0.05-8	s-h	20ms-s	0.25

3 ELECTRIC VEHICLE

As a compound solution for energy crisis and environment problem, Electric Vehicle(EV) has drawn more attention and approval with the decreasing of battery cost and policy and regulatory promotion. While the consistent habit of charging by EV owners would bring new increase of the power system load, which will widening the peak/valley difference as well as economic benefit. In the view of grid operation, Electric Vehicle has the following characteristics: 1) Mobility Characteristics: it is accessed in the power grid without any limitation and cannot be predicted precisely. 2) Non-linear load. A series of problems including electric quality would be brought into the power system as the EVs are accessed into the grid. 3) Although EV bring into grid pressure while charging, it can also be dispatched and take advantage of the sufficient power in the night. This benefit not only the equipment but the economics. 4) As for the big grid, electric vehicle can be seen as mobility storage. With the proper control strategy, it can have interactive with other distribution generation. There are possibility in optimization and coordinate operation.

3.1 Power battery of Electric Vehicle(EV)

3.1.1 Introduction of Electric Vehicle

Adopting the non fossil fuel as the power resources, integrated with the advanced technology in controlling and drive, the renewable energy automobile is the integration of the advanced principle, new technology and new structure. Classifying according to power source, there are mainly three types electric vehicles: Hybrid Electric Vehicle (HEV), Electric Vehicle (EV) and Fuel Cell Electric Vehicle (FCEV). HEV is improved in the basis of traditional fuel with electrical machine to acquire a better output at low speed. EV is using battery to replace combustion engines and work in motor drive. The difference in FCEV is that the electrical is produced by chemical reaction of methane and hydrogen.

3.1.2 Category and Characteristics

According to the characteristics of electric vehicle, power battery should have a larger specific energy and specific power, long cycle life and a wide operating temperature range and so on. Currently the main power batteries in the market used in electric vehicles includes: lead-acid batteries, nickel hydride batteries and lithium ion batteries[41].

Table 3-1 Characteristics of different type of battery

Characteristics Type	Specific energy (Wh/kg)	Energy density (Wh/L)	Ratio power (W/ kg)	Power density (W/ L)	Life cycling (times)	Price (dollar/ kWh)
LAB	35-50	65-90	100-150	120	500-800	80
Ni-Zn battery	70-85	——	170-220	——	300-400	150
Ni-Ir battery	50-60	——	160-200	——	800-1000	200
Ni-MH battery	70-100	135-150	180-250	160	1500-2000	300-400
Ni-Cd battery	50-60	80-110	160-200		1000	120
Na-S battery	100-120	150	130-150	300	1100	1000
Li-ion battery	100-120	170-250	300	——	1200	500-600
Zinc-air battery	180	——	150	——	100	100-150
Al-air battery	200	250	100	——	500	100-150
ZEBRA	100-120	132	200-250	——	1000	300-400

Lithium-ion batteries have a greater specific energy and specific power indicators, but as the use and manufacture time period is not so long as lead-acid battery, their technology isn't that developed relatively. However, lead-acid battery has the potential risk of contamination, nickel-tin batteries also contain toxic substances. Other batteries, such as: sodium-sulfur batteries, sodium nickel chloride batteries all have their own disadvantage of either the environment or the technical aspects, which is not conducive to the promotion. Several common battery performance are shown up in Table 3-1.

Because of its superiority in performance, lithium battery attracted considerable attention, but they are expensive. While in recent years, as technology advances, costs are constantly reduced. Currently common types are lithium cobalt oxide, lithium manganese oxide and lithium nickel oxide is the material of lithium ion battery and lithium iron phosphate materials for lithium-ion battery. Compared with other lithium batteries, lithium iron phosphate ($LiFePO4$) battery has a large charging and discharging current, better cycle life and favorable changes in temperature performance. It is considered the best lithium battery and has a good application on energy storage power and consumer goods.

3.1.3 EV Battery Structure

The battery of TESLA electric vehicle uses the NCA series (nickel-cobalt-aluminum system) 18650 lithium cobalt oxide battery supplied by Panasonic. The capacity of single battery is

3100 *mAh*. Compared to other electric car battery, 18650 battery technology is more mature in different property index. It is almost twice of lithium iron phosphate in the energy aspects, which means that, in the case of the same volume, it can store more electricity. The following table 3-2 compares Tesla battery with other brands of electric vehicle batteries, the mileage has been converted into the distance by pure electricity, which comes from the official data.

Table 3-2 Comparison of different type of EVS

Types	MODEL S	Prius Toyota	Chevrolet Volt	BYD e6	Nissan
Anode material	18650NCA	$LiMn_2O_4$	Li(NiCoMn)O2	$LiFePO_4$	$LiMn_2O_4$
Battery supply	Panasonic	Panasonic	LG	BYD	AESC
Total capacity	85kWh	44kWh	16kWh	60kWh	24kWh
Mileage	426km	20km	62km	300km	160km
Battery guarantee	8years	3years/10w km	8years/16w km	5 years/10w km	16w km

The battery TESLA electric vehicles comprises a number of 18650 lithium batteries, which requires the combination of thousands of batteries in a reasonable manner.

MODEL S of 85kWh battery cells uses totally 8142 of 18650 lithium batteries. These lithium batteries were first formed by the combination of the battery bricks, within each cell contains a number 18650 battery. Then, several cell blocks will form a battery slice. Eventually, a number of cells to form a battery assembly, located in the bottom body. Battery capacity is determined by the number of 18650 cells related.

TESLA MODEL S can be divided into three parts: the body, chassis and battery. The battery in the car floor is tiled and protected by rugged plate covers.

3.1.4 Battery Management

From the foregoing description and summary, battery technology remains a key constraint for the development of electric vehicles. To deal with problems that can easily arise such as fair use, temperature control, timely problems detection, we need battery management system (BMS) to improve battery efficiency and reliability through effectively monitoring and battery management

As mentioned above, power battery is achieved by assembling a number of batteries. In fact, not all cells are in the same state. If for the reason of individual batteries damaging or not working properly that cause the entire battery group cannot work, it is an inefficient behavior. Battery management system carries on the unified management for the entire battery module. According to the battery voltage, current, temperature and other parameters to determine the working status of the battery, BMS ensures the smooth operation of the motor car, which includes charging mode selection and execution, battery detection, protection and other major functions. Take TESLA electric cars for example.

Seen from the above TESLA 18650 lithium cobalt oxide used in electric vehicles could meet higher mileage life, but its stability at high temperature as compared to nickel-cobalt manganese lithium (NCM) and lithium iron phosphate is not satisfactory. Therefore, in terms of security there is a need to have BMS to detect and protect.

Each 18650 lithium cobalt oxide battery pack contains the security system, and is distributed to each segment. There are fuses at both ends of lithium cobalt oxide 18650. When the battery is overheating or excessive current, the fuse will cut off the battery in order to avoid an abnormal situation (overheating or excessive current) which may affect the entire battery pack.

Security device is the last barrier. It cut off a cell when there is a problem. If it comes to replacing, the entire battery pack can be replaced in the unit of slice. Each battery is connected in parallel, and different slices and bricks are connected in series. That is, in the process of driving, when a battery has some problems, the vehicle will not stop and the problem will affect only the vehicle mileage.

The reason of monitoring the working status of the entire battery pack and control system of each cell is due to the battery monitoring device which can monitor the status of each battery cells brick. Apart from the current and voltage, it can also identify the cell operating temperature, the relative position of each tile, and whether there is smoke.

Battery temperature is a key factor affecting performance[42]. The conditions will fluctuate when it is too high or too low. Thereby the system needs to constantly balance each battery temperature. The above-mentioned these guarantees on security and battery performance have benefited from this design battery management system.

3.1.5 Lifetime Calculation

The principle of charging and discharging of the battery is constantly engaged in its internal reversible chemical reaction. When the charging number increase, active chemical substance is reduced, charging efficiency become lower, which will eventually lead to the end of battery life. There are working and non-working factors that affect battery life. Working factors include: the charging and discharging speed, temperature, and depth of each charge and discharge which is lost and influenced. Non-working factor refers to the internal battery material corrosion, the active substance shedding and so on. Generally speaking, the smaller the depth of discharge of the battery can protect the active material inside the role, so that the battery life can be extended.

Since the battery purchase is a one-time investment. In the actual calculation, impact on economy not only embody in the cost, it is also reflected in the calculation of battery life. In this thesis we will convert the investment into every charge and discharge cycle. In order to consider running cost of storage accurately, this section we use the rain flow algorithm and simulation in MATLAB to analyze and explore the life of the battery.

1) Rain flow algorithm

Battery life is closely related to working mode, temperature, peak current, charge-discharge cycle. Generally speaking, the greater the depth of discharge (DOD), the shorter the cycle life. Rain flow counting method calculates a single charge and discharge loss of the entire battery life by simulating different cycle module. Then multiply the single loss by the total cost, the cost consumed per discharging time can be gotten.

Rain flow algorithm was proposed by the British engineer Matsuiski and Endo, more than 50 years ago, and is widely used in the engineering sector, especially in the calculation of the fatigue life. Features of this method is to count based on the study of the non-linear relationship between strain-time, which is set in advance a series of cycles, and then follow the loop recording in the sample. Principles calculation based on battery discharge depth by rain flow counting method is as Figure 3-1:

(1) Rotate the power - time curve clockwise by 90 °. Rain stream begin from the recording start and the inner edge of each peak.

(2) Rain stream flowing along the track end (eaves) and drop vertically until there is a maximum (or minimum value more negative) at the opposite side than the original maximum (or minimum)

(3) When the rain flow encountered rain from the top line (the eaves) dripping, stop the flow and form a loop.

(4) According to starting point and ending point, draw each cycle, taking out all the loop one by one, and record its peaks and valleys.

(5) The length in the horizontal direction is the depth of discharge of the cycle.

The battery charge and discharge application specific as follows: abscissa stands for battery charge (SOC), the vertical axis is time. The first rain flowing from the starting position, from 0 to point 1, and then fall into 1'. It runs following a straight line along the eaves to 5, and then fall. The second rain flows from 1 to 2, and 2 to 3, falling from 3 to 3' and continue flowing along new track downstream before meeting the stream from roof above at 1' and then stopped. Similarly continue, you can get counting loop module, as indicated in the figure 3-1: 3-4-3', 1-2-1', 6-7-6', 8-9-8'. By measuring the cycle span in the horizontal axis, we can get different depth of discharge in different cycles.

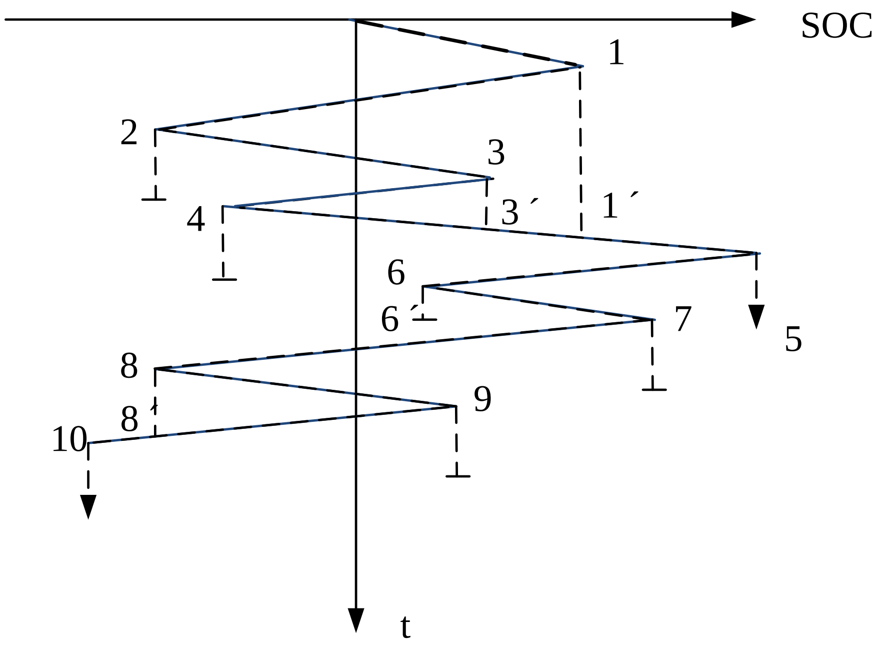

Figure 3-1 Rain flow algorithm to calculate the storage Lifetime

2) The calculation of loss of life

The accumulated discharging damage can be presented in the following equation:

$$D = \sum_i \frac{N_{c,i}}{N_{f,i}} \tag{3.1}$$

While, D stands for the accumulated damage. The maximum discharging depth is divided into i layer. $N_{c,i}$ is the number of cycles in layer i, $N_{f,i}$ is the maximum number of cycles in layer i. The battery will be used up when D reaches 1.

After getting the life damage of every charging discharging period, we can get the cost for the charging discharging period Closs by the following formula, COST is the investment cost of the storage equipment:

$$C_{loss} = COST * D \tag{3.2}$$

Programming in MATLAB (the routines of rainflow algorithm is packaged and download from internet, the connection routines and how to use the packaged algorithm are programmed by myself) according to rain flow algorithm, we can get the life damage according to the charging discharging behavior. The figure below shows three different DOD of the same battery in 24 hours a day:

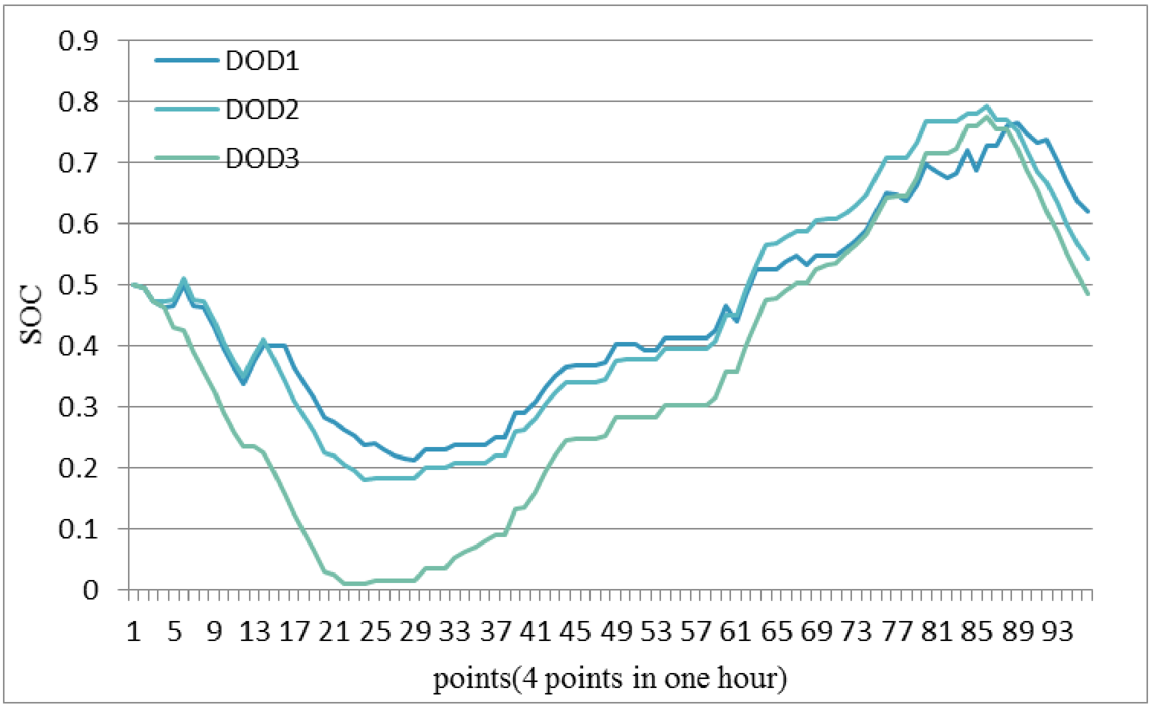

Figure 3-2 Different charging discharging curves of one same battery

According to the figure, the electric quantity is counted every 15 minutes, all together 96 sets of data. From the figure we can get that the DOD of DOD1 was kept between 20% and

80%, While, DOD2 has a larger span over depth of discharge and DOD3 is the largest. DOD3 carries an entirely discharge in the 6th hours. Calculating the damage in the three battery by the program we can get the damage respectively as follows:

$$\begin{aligned} &Damage\ DOD\ 1 = 5.6*10^{-4} \\ &Damage\ DOD\ 2 = 6.03*10^{-4} \\ &Damage\ DOD\ 3 = 1.1*10^{-3} \end{aligned} \tag{3.3}$$

The damage of DOD3 is the largest because the depth of charge is the biggest. DOD 2 is following and DOD1 is the smallest, which is consistent with the analysis above. It is reasonable to charge and discharge between 20% and 80% in the point of view of driver habit and battery quality. So, in this work, we set the maximum and minimum limitation as 20% and 80%. The result of DOD1 and DOD2 are more suitable, we use their daily life damage as in the following mathematical model to calculate the investment cost per day.

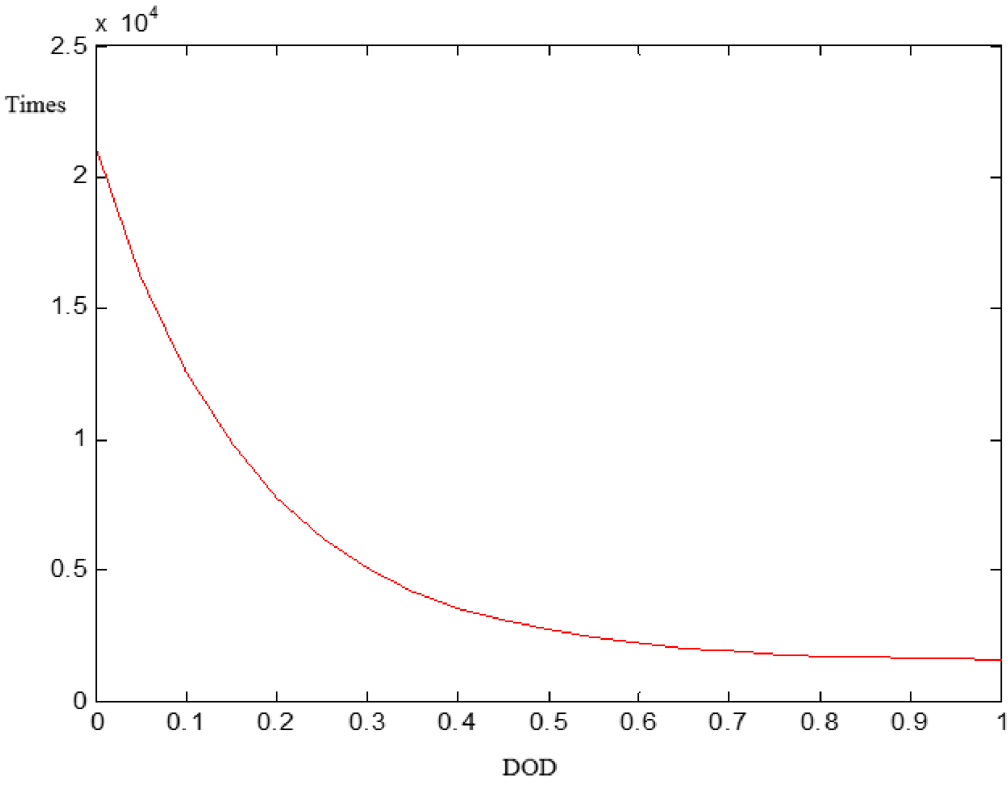

Figure 3-3 Relationship between DOD and discharging times

3.2 Trip Characteristics and Charging Load Calculation

3.2.1 Charging Mode

The charging mode of electric vehicle is related to the user's practical experience and the problem of grid capacity planning and scheduling of the economic operation. In general, there exists two types of battery supplementary mode. One is plug in mode, the other is changing mode by replacing the empty battery, which is divided into fast charge and slow charge.

1) Battery swap mode

The swap stations are distributed in different places in the city but they are gathered together and transported to the fixed station to charge together. In this way, the empty battery can be charged concentratively in the valley period and fully take advantage of the low price electricity at night as well as smooth the load fluctuation.

The use of mechanical devices helps to minimize the time to complete the replacement of empty and well charged batteries. Scientists in Japan developed automatic electrical device to replace the battery even with just 59 seconds.

While the one off investment is large and the battery damage needs supervision. Relevant law and regulations are required to protect the profit of the users. All by all, the charging by different mode still needs to connect to the grid to get energy. Swap mode has a very large charging load and an influence on the grid which we can’t ignore, including the load and the precise location to connect in. Besides, the operator and logistic are also an index which will influence the whole process.

2) Plug-in mode

Electrical vehicles are connected to the grid by plugging in the port directly anywhere if there is a port. It is mainly divided into fast charging and slow charging. In general, slow charging is suitable for residential parking, garage parking and other companies. Usually it has a large number and the distribution is more dispersed, fully taking into account the user's daily habits. It mainly use the electricity at night or the long spare time to conduct charging. Due to the long charging time and small charging power, the power quality is less affected, and this will not have serious impact on the battery life, usually 8-10 hours of the constant pressure or constant current.

The time of fast charging mode is less than one hour and the power is different. For example: Tesla needs only 40 minutes to charge 80 percent of the full electricity, but the remaining 20% will be filled up in the same amount of time. This is designed because when it is nearly fully charged, reduced current is needed. Besides, 80% of the total amount is good for the battery.

Fast charging time meets the needs of driver's demand and is more often used in the case of long-distance traveling. On the other hand, large charging current and charging power leads to the high temperature, and affects battery life. As a non-linear loads, electrical vehicles would bring harmonics waves into the grid which will affect the power quality. In addition, due to the large charging power and current during the rapid charging, the requirements for the power grid and charging infrastructure are also higher.

3.2.2 Trip Characteristics and Charging Load Calculation

Electric vehicle battery charging at this stage is mainly at constant current - constant voltage two-step charging method. Firstly, using constant current charging method, with the variously charging of the battery terminal voltage, the charging power is also changed until the voltage reaches a threshold. Then the constant voltage charging mode status, charge current and charge power are decreasing. The charging power in the constant voltage charging period can be approximated as constant power charging for the sake of simplicity. On the basis of constant power charging, we will make the electric vehicle charging load analysis and forecasting by analysis the characteristics of electric vehicle owners.

1) Charging start time

Since the presentation of the dispersion of electric vehicles, we need to predict the load of the electric car and analyze different with normal cars. Electric vehicles have a relatively fixed driving characteristics because of the constraints of battery. Electric car owners' trip depends mainly on their driving habits and battery capacity. Without considering the buses and other public electric vehicles' travel characteristics, residents in an industrial park district charge electric vehicles in general only once a day. Due to the high idle probability of electric vehicles during the working day and fixed habits for people going to work, ignoring the variety of connection time in the link, it can be assumed that the last minute of user returns to their location is the start charging time. According to the literature [43, 44], US Department of Transportation for the US vehicles survey (National Household Travel

Survey, NHTS) tells that the probability distribution of the last time residents return to their home is shown below.

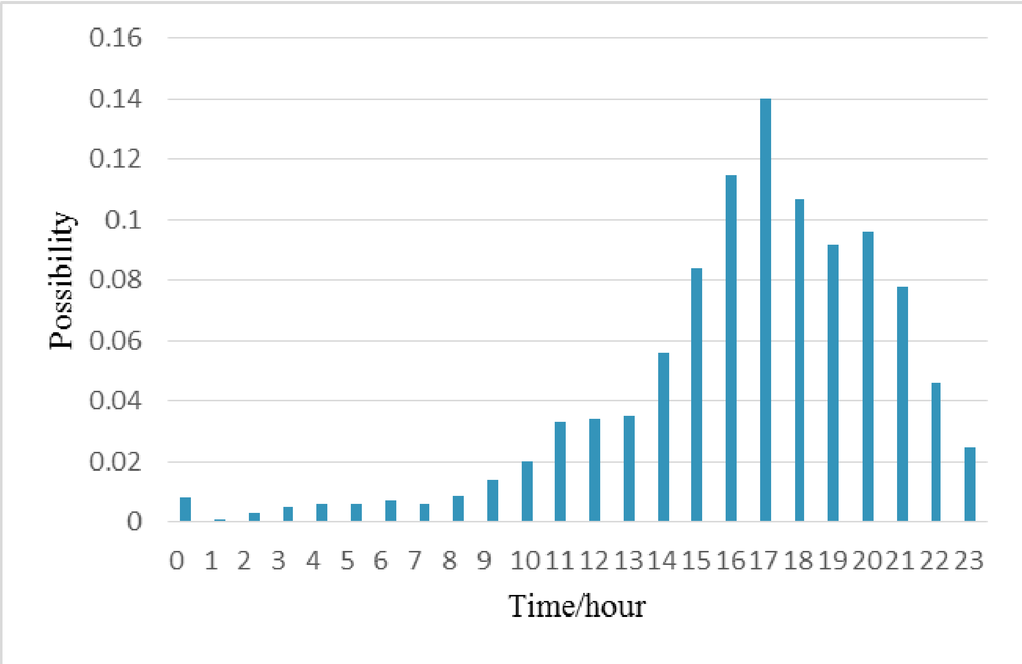

Figure 3-4 The probability distribution of last time vehicle return to their home

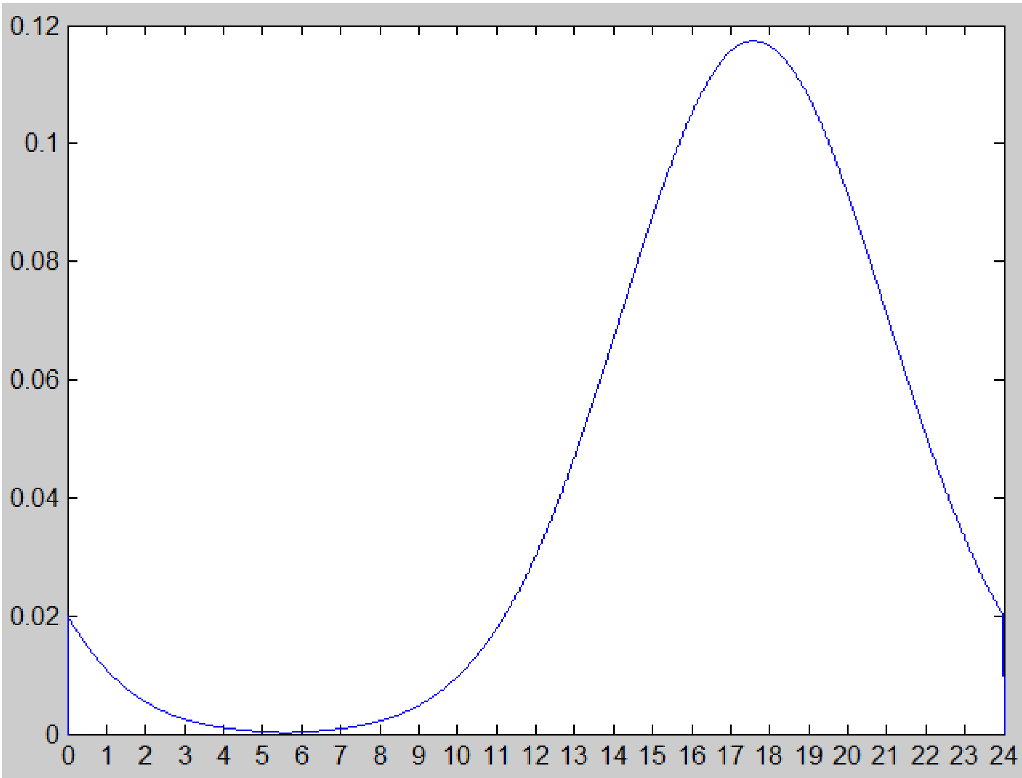

Figure 3-5 The probability density fitting curve of vehicles return to their home

As it can be seen from the figure above, the last time of returning vehicle reached to thePeak at 17:00 and are concentrated between 14:00 and 22:00. Based on the assumptions above, the owners charge the vehicle immediately after return, the start charging time is distributed according to the figure. The figure can be estimated using the maximum likelihood method and fitting as the probability density curve of start charging time in continuous time, as shown in Figure 3-5.

The probability density function of start charging time T_{sc} is:

$$f_{Tsc}(x)=\begin{cases}\frac{1}{\sigma_s\sqrt{2\pi}}\exp\left[-\frac{(x-\mu_s)^2}{2\sigma_s^{\ 2}}\right], & (\mu_s-12)<x<24\\ \frac{1}{\sigma_s\sqrt{2\pi}}\exp\left[-\frac{(x+24-\mu_s)^2}{2\sigma_s^{\ 2}}\right], & 0<x<(\mu_s-12)\end{cases} \tag{3.4}$$

Where $\mu_s=17.6, \sigma_s=3.4$.

2) Charging duration

The charging duration of electric vehicles are related to the SOC. Assume that all the electric vehicles are fully charged before the daily trip, so the battery they should charge in the evening is the same as they spend on the way, which is a linear relation to the mileage they drive in the trip. According to statistics of NHTS, the daily driving mileage data of vehicles is distributed as shown in Figure 3-6.

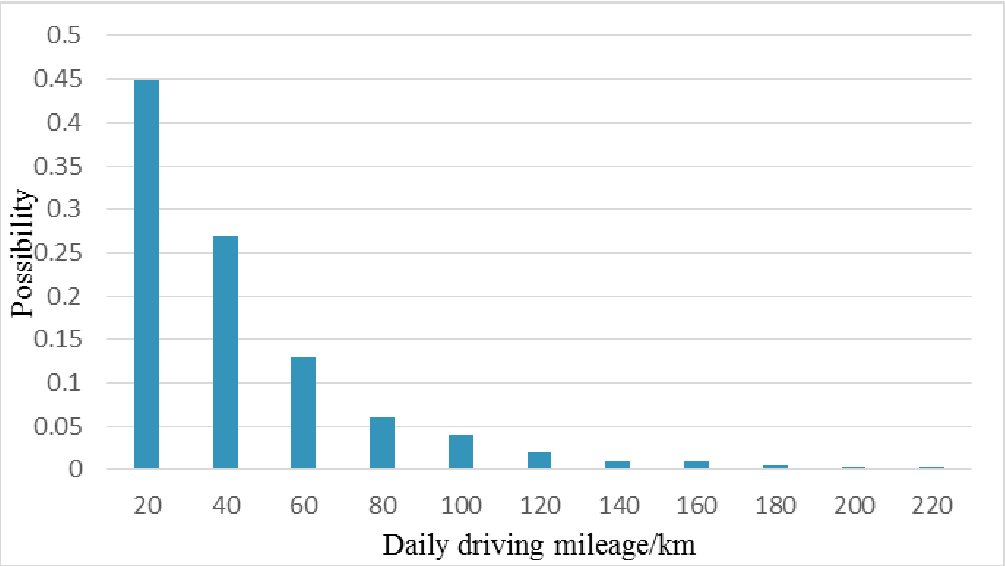

Figure 3-6 The daily driving mileage data of vehicles

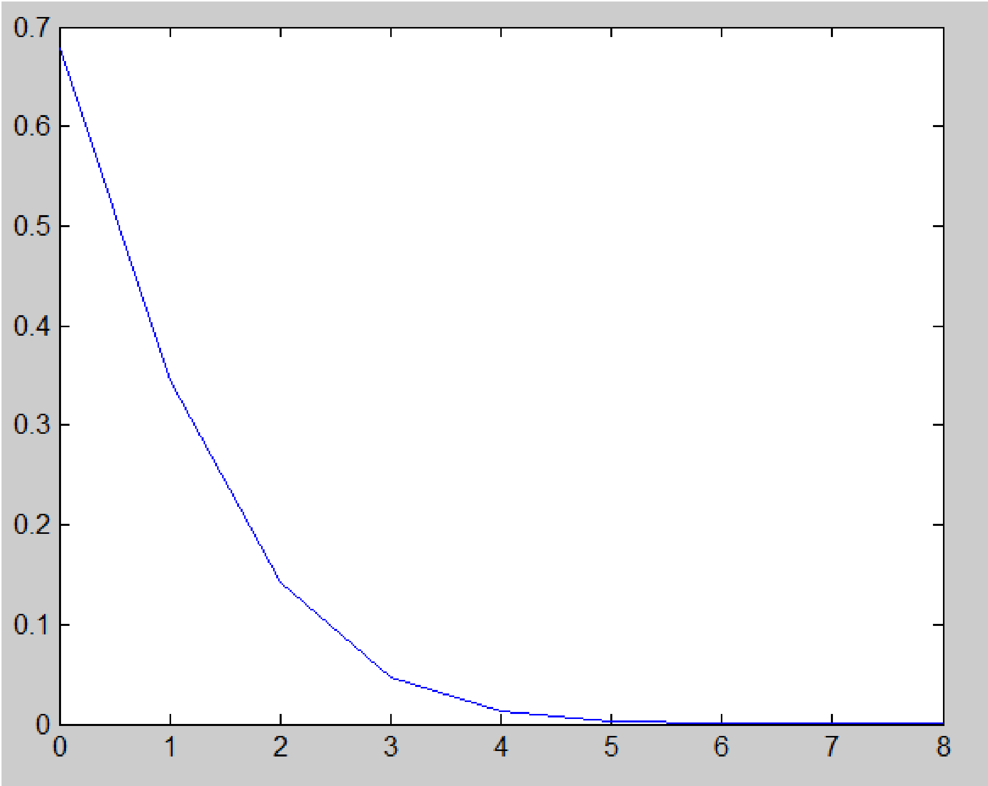

Figure 3-7 The probability density curve of duration by continuously charging

As it can be seen from the figure, the day driving mileage in 20 miles has the maximum probability, while little probability lies beyond 100 miles. By the day driving mileage of electric vehicle, the charging duration can be estimated as:

$$T_c = \frac{LW_{100}}{100P_c\theta} \tag{3.5}$$

Where T_c is the charging duration, presented in hours, L stands for the day driving mileage, W_{100} is the consumption per hundred kilometers, kWh/km, P_c is the charging power, kW, θ is the charging efficiency. According to related reference, we use electric vehicles power consumption 15kWh per hundred kilometers, charging electric power P_c of 3.5kW and 0.9 of charging efficiency. The charging duration can be get by multiplying a constant to the data above. Using MATLAB curve fitting tool, the probability density curve of duration by continuously charging can be obtained as shown in Figure 3-7.

3) Charging load calculation

The results of the analysis above reveal the probability distribution of initial charging time and charging duration of electric vehicle. This section will estimate the charging load expectations by using Monte Carlo based on the probability distribution of both[45].

Monte Carlo method is carried out by designing a large number of stochastic process repeatedly generate time series and calculate statistics to study the distribution characteristics. Through the establishment of a random variable to generate electric vehicle battery at different times and determine its charging requirements, we can finally obtain statistical charging expectations by a large number of experimental results.

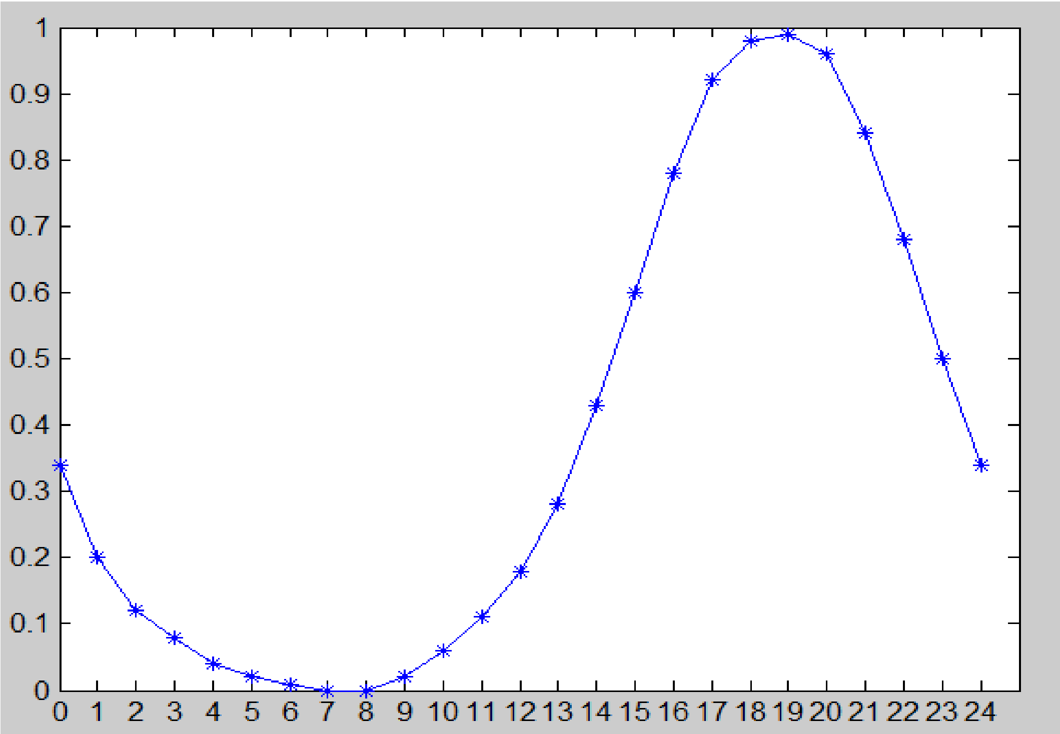

Figure 3-8 The charging load expectation curve of electric vehicle

Specific steps are as follows:

Step1: Build two N-dimensional arrays according to the probability density function of electric car charging start time T_{sc} and charging duration T_c, using a random function to make the numbers randomly arranged.

Step2: Build a two-dimensional array of 24 * N to represent the state of charge and discharge of an electric car within a day, make a mark when it is the state of charge.

Step3: Repeat the experiment and calculate the number of charging state n, the ratio of n and N are the charging expectations of electric vehicle at a certain time. Repeat the above process to obtain the expectation of other times points. Take an average value after repeated.

As shown in the following figure is the EV charging load expectation curve obtained by using Monte Carlo method. It can be seen from the figure that charging load is minimum in the morning 7:00 and maximum at 19 o'clock.

3.2.3 Electric Vehicle Coordinate Charging to Smooth the Fluctuation of Load

Because of the driving habits and characteristics of the trips of electric vehicle owner, the charging peak of EV and original peak load are in the similar time. If we still continue disorderly charging without coordinated according to the peak and valley time, the difference between peak and valley will further increase, which is not only conducive to the economy, but also threatens security and stability of the power grid. Therefore, it is necessary to study on the coordination of charging time. This section is going to achieve the purpose of optimizing by changing the load of the charging station within reasonable dispatch[46].

There are three ways for electric vehicles to intergrate into the big grid to optimize the load:

1) Normal load: the charging load is like the normal load without dispatching.
2) Shifting load: Adjusting the charging time to the night and smoothing the fluctuation of the load.
3) As a source as well as the load: V2G, it can deliver power to the grid reversely if there is a need.

Objective function: The target is to smooth the fluctuation of load and minimize it.

$$min\, O = min\sum_{n=1}^{24}\left|P_{ln} + \sum_{1}^{k}P_{nk} - P_{av}\right| \tag{3.6}$$

$$P_{av} = \frac{1}{24}\sum_{n=1}^{24}P_{ln} \tag{3.7}$$

Where O is the objective function, n is the number of hours, k is the number of EV. P_{ln} stands for the original load. P_{jk} is the charging load of EV, P_{av} is the average value of original load. The whole equation is to minimize the fluctuations after adding the charging load to the original load.

Besides, because EV coordinate dispatching could take use of the unused power in the midnight and charging in low price, which gives a reason for load shifting and what's more, it can send electricity back to the grid with a high price by V2G to make profit as well as peak load shifting. Smoothing the fluctuation and economic profit are two target that are different from each other but supply each other.

Constraint function

We mainly consider from capacity and electricity to constrain the well-organized charging. Capacity for power plants, power charging device and battery charging power need to be considered. Electricity in the swap station should be within a reasonable range and ensure that adequate power supply to the need for electric vehicles in different moments.

Constraint 1: Charging power constraint

$$\left|P_{nk}\right| \le P_{nkm} \tag{3.8}$$

Where P_{nk} stands for charging and discharging power of kth electric vehicle in the nth hour. When P_{nk} is positive, it means charging status, otherwise it's negative, which can be understood as an electric car sending power back to the grid by V2G. P_{nkm} represents the upper and lower limitation of charging and discharging. It is determined by the minimum value of the maximum battery charge and discharge power P_{max1}, exchange power limitation of the distribution transmission line, such as distribution network transformer capacity P_{max2} and the maximum discharge power P_{max3} that the battery can withstand inside the swap station. The lighting and office consumption is negligible. P_{nk} can be taken to zero.

Constraint 2: Charging energy electricity

$$Q_n = Q_{n-1} + P_n \Delta t - E_n \tag{3.9}$$

$$Q_{n\min} \le Q_n \le Q_{n\max} \tag{3.10}$$

Where Q_n is the charging energy electricity of the swap station in time n, P_n is the charging power of swap station in time n, E_n is the energy electricity swap demand of electric vehicles in periods n, which is positive correlated with the number of electric vehicles and the energy electricity of the difference between the starting point and ending point.

$$E_n = \sum_{k=1}^{m} (E_{enk} - E_{snk}) \tag{3.11}$$

Where m is the number of electric vehicle in time n, E_e, E_s were the energy electricity of electric vehicle in start charging point and ending point.

q_n is the storage of electricity at time n. Assume that the number of EV battery in the swap station is dynamic equilibrium, taking into account that the SOC of the battery is in the range of 20% to 100%. The energy electricity stored in the station is as follows:

$$20\%\mathrm{N}Q_N \le q_n \le 100\% NQ_N \tag{3.12}$$

Where Q_N is the rated capacity of the battery, N is the battery considered.

We can get the following equations by substitution:

$$20\%\mathrm{N}Q_N + E_n \le q_{n-1} + P_n \Delta t \le 100\% NQ_N + E_n \tag{3.13}$$

$$Q_{nmax} = 100\% NQ_N + E_n \tag{3.14}$$

$$Q_{n\min} = 20\% NQ_N + E_n \tag{3.15}$$

Q_{nmax} and Q_{nmin} is the function in time n, determined by E_n, which is the electricity demand of EV at time n. At time n, the amout of E_n of electricity will be taken away by car owners. We can get the amount of energy electricity for a single car and the total energy electricity by multiple the number of cars.

3.3 Case Study

1) Basic data

The coordinating scheduling scenario of electric vehicle swap station is described as follows:

(1) The day is divided into 24 segments, assuming that charging power is a constant.

(2) We neglect the business model, which means how to organization and operation. The owners of EV immediately charge the battery when they finish the driving.

(3) Supposing there is no time limitation for the possibility to connect the grid, the dispatching of EV is carried on in all day.

Taking an industrial district as example, the original load forecasting is as the figure below. The data is partly adapted from the reference[47].

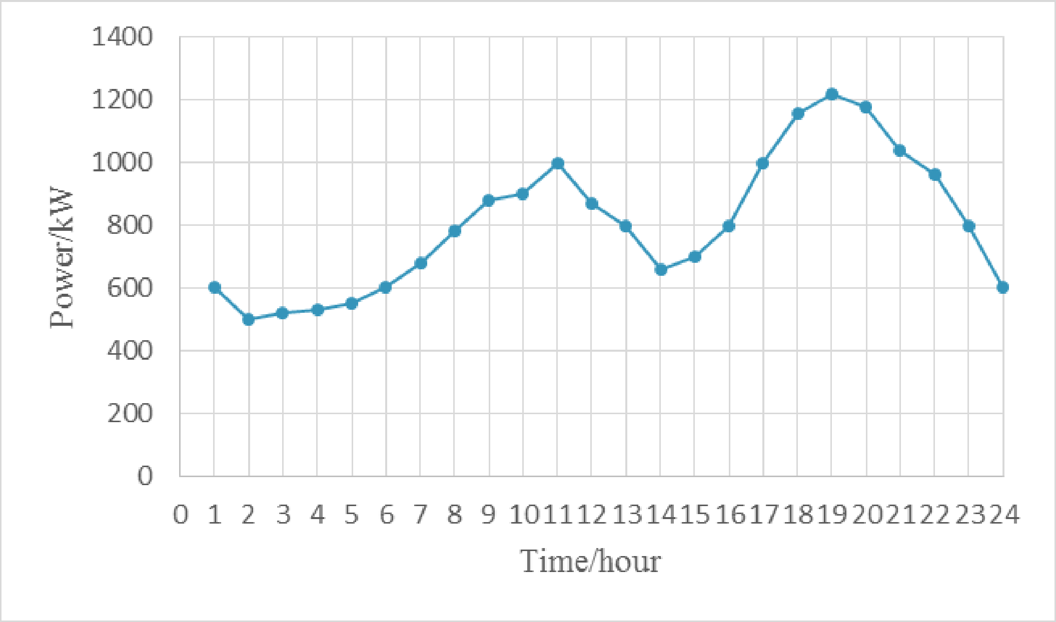

Figure 3-9 The original forecasting load of an industrial district

The industrial district has a swap EV station and 20 electric cars, each with a set of electric car battery (10 cases). The number of battery group and charger device are correspondence. Using QND602-400 type charging machine, the whole charging power of station is 120kW. Distribution transformer capacity of the district is 2.2MW, the capacity of electric vehicle battery energy storage system is 65kWh.

The total amount of EV battery electricity that can be stored： $65\text{kWh} \times 20 = 1.3\text{MWh}$

The maximum charging power of the station： $6\text{kW} \times 20 = 0.12\text{MW}$

According to the reference[48], the SOC when a car return obey the normal distribution with the expectation of 40%. The amount of electricity EV need to swap is:

$$(100\% - 40\%) \times 65\text{kWh} = 39\text{kWh}$$

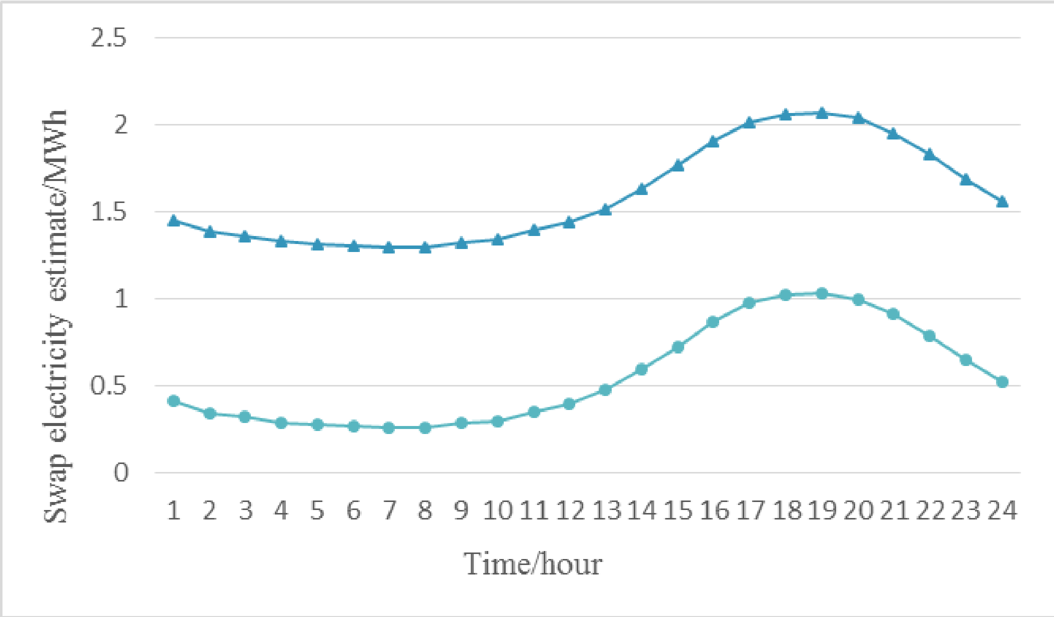

Figure 3-10 The estimated upper and lower boundary of EV's swap electricity

According to the result above, we can get the estimated upper and lower boundary of EV's swap electricity as Figure 3-10.

2) Result analysis

In this section, we will show the result and analysis of the objective and constraints after programming in the software CPLEX.

Table 3-3 The dispactching schedule after coordinate charging

Time/h	Charging load/kW	Time/h	Charging load/kW	Time /h	Charging load/kW
1	120	9	-74.5833	17	-120
2	120	10	-94.5833	18	-53.7
3	120	11	-120	19	-31.2
4	120	12	-64.5833	20	-85.8
5	120	13	5.416667	21	-120
6	120	14	120	22	-120
7	120	15	105.4167	23	5.416667
8	25.41667	16	5.416667	24	120

The table above is CPLEX software optimization results, which is the charging power scheduling of EV in the case of the electric vehicle charging involved in the coordination in order to stabilize the load fluctuation. As can be seen from the table, in the period of night time, the swap station take advantage of the adequate electricity to charge for the battery, while in the peak period of 19:00 to 22:00, EVs give back energy to the grid reversely through V2G technology in order to relieve pressure of the grid, initial realizing "load shifting" and achieving the purpose of a smooth load fluctuations.

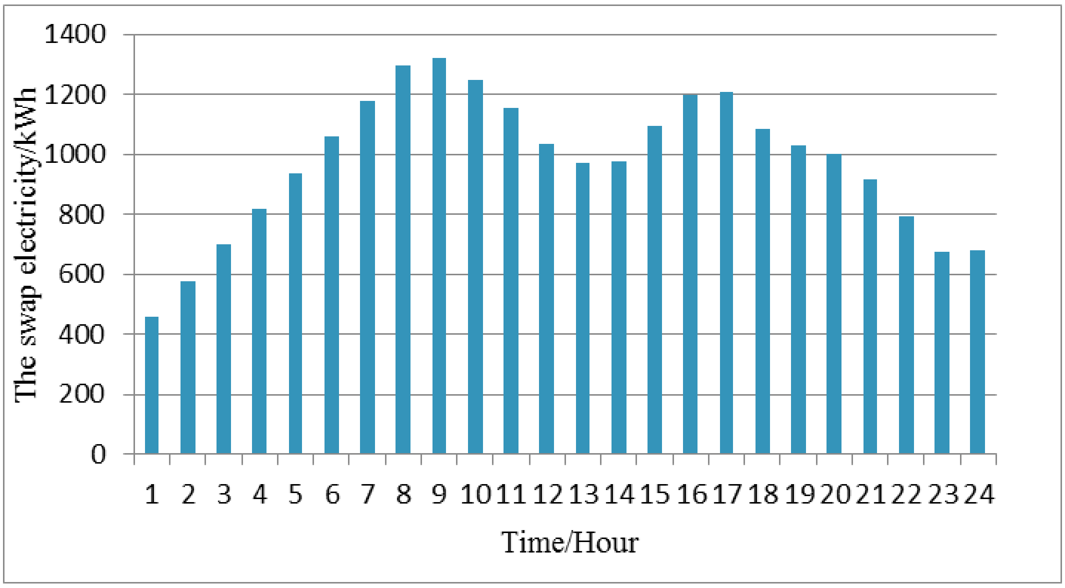

Figure 3-11 The swap electricity of Evs E_n at 24 hours

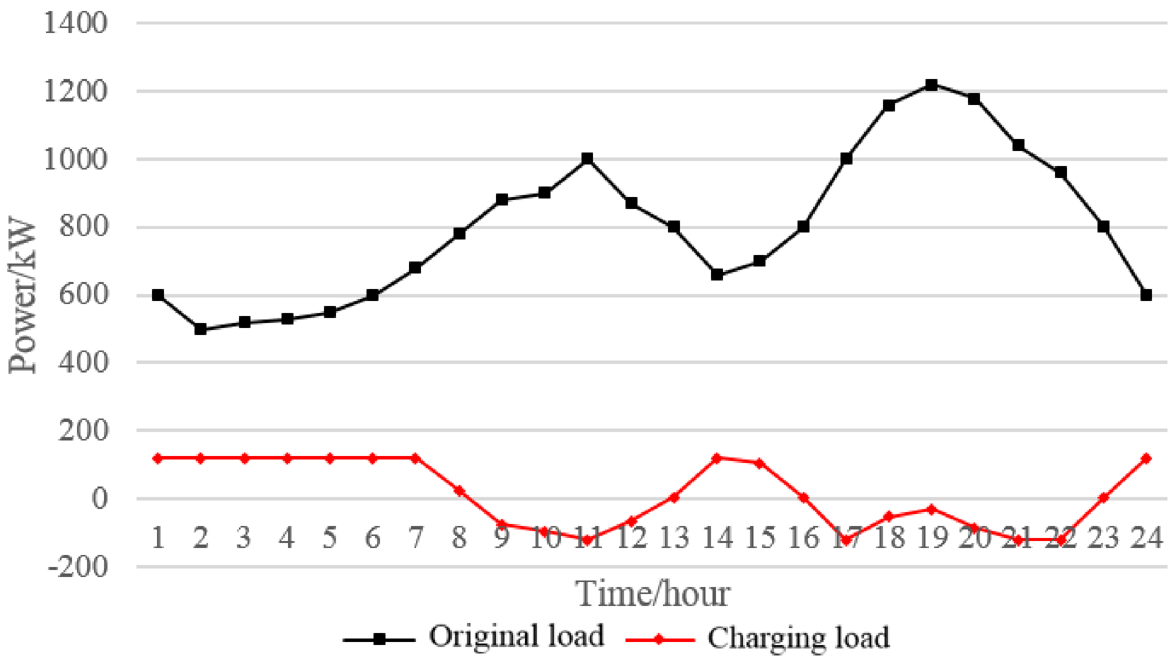

Figure 3-12 The curve of original load and EV charging load

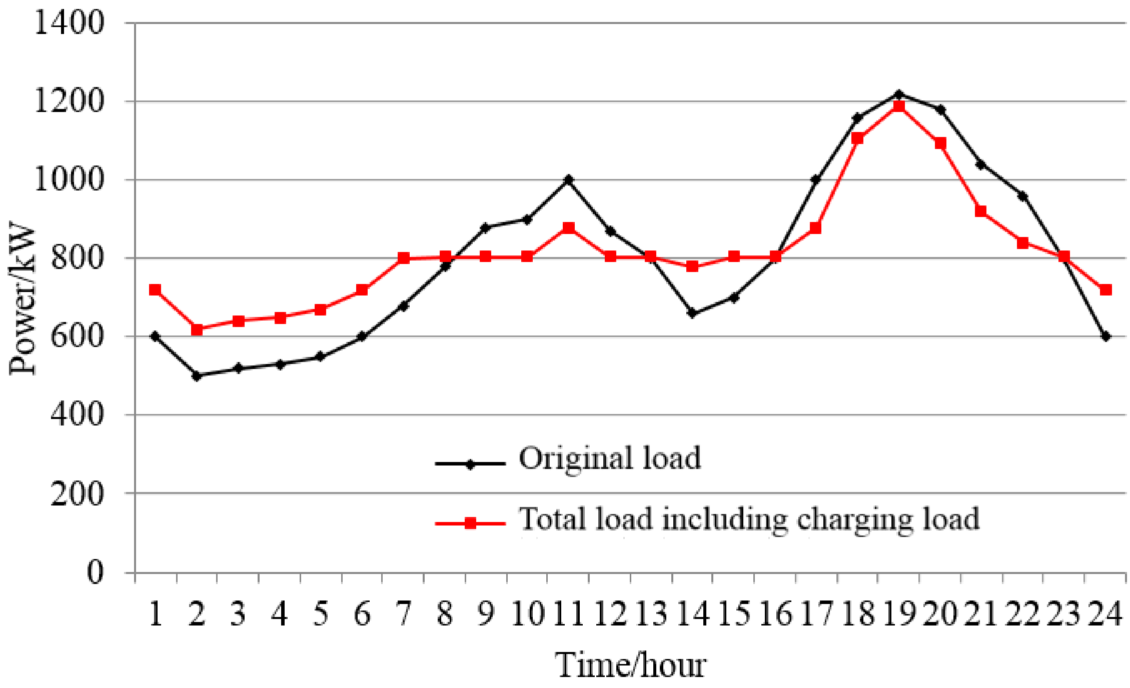

Figure 3-13 The load curve result before and after optimization

Figure 3-11 shows the swap electricity of Evs En at 24 hours. Trend can be seen from the graph that peak reaches at 9:00 and 17:00. Before 7:00, it is charged with the maximum power during the valley price period. In the corporate effect of peak load and peak price, electricity from the 9:00 start to reduce. After 17:00 o'clock, due to big consumption, battery gives back electricity through V2G and lead to an overall decrease. The difference between adjacent time is the swap power of the EV load.

Figure 3-12 shows the curve of original load and EV charging load. We can see the charging load accounted for the proportion of the original load of between about one-quarter to one-third of the original load and plays a certain influence to the original load. The trend of charging load and original load was contrary and complementary for each other.

Figure 3-13 is the comparison figure of load curve before and after optimization. The black line is the original curve and the red one is the curve after optimization. We can see clearly that the curve with the coordinate charging of EV is more smoothly and have less peak-valley difference, which proves that in the premise of fulfilling the demand of EV owners, the coordinate charging of EV can help charging in the night valley and giving back the electricity through V2G during the peak period. This can help shifting the load and improving the load curve by optimization.

4 THE ECONOMIC OPTIMIZATION MODEl FOR MICROGRID WITH EV

Micro grid is flexible in operation mode and dispatching performance. It can also achieve some autonomous functions, such as self-control, self-protection and self-management. The economic optimization operation of micro grid is a very important aspect for the energy-economy of the micro grid system.The output of its distributed power supply varies with the climate and environmental variation, while energy storage unit and the power grid can also exchange energy with the micro grid. On these terms, economic operation of micro grid is different from that of the power systems. In this chapter, the energy management of the micro grid is first analysed, then in reffering to the analysis of the distributed power and electric cars in chapters 2 and 3, the ecomonic model is established according to the characteristics of the micro grid, and also the objective functions and constraints.

4.1 The Energy Management Processing of Micro Grid

Compared with the traditional energy management systems of power system, energy management processing of the micro grid system is more complicated, which is closely related the the structure of the micro grid. The main difference are shown as follow:(1) micro networks includes distributed power, such as solar, wind power, fuel cells, gas turbines, batteries, and these power supplies are connected by power electronics equipments and micro grid transmission lines, where the photovoltaic, wind power is intermittent random natural energy. (2) the energy flow between the micro grid and battery or the power grid is bi-directional, and the batteries exchange energy with the micro network to achieve the optimization of the system. (3) the micro grid is influenced by both of the the access methods of batteries and the driving habits of the electric vehicle driver, which is random and dispersible. In addition, under conditions that allow micro grid transfer power to the external network, the micro grid and the external power grid can exchange power, while when the micro grid does not allow to connect to the power grid, the external power grid can transfer energy to the the micro grid monodirectional.

Therefore, the key point of the research of the energy management system of the micro grid systems mainly focuses on the similarities and differences between the distributed energy generation systems and the conventional energy sources, as well as optimally dispatching methods of the system consisting of a variety of distributed energy systems. We should proceed from the specific aspects as following[49]:

1) Modeling of micro grid system: establishing the mathematical models of the distributed energy units of each constituent parts of the micro grid, including steady state, transient state and stochastic model of the renewable energy of each unit, and also including the economic model of optimally dispatching. On the basis of the mathematical model of the distributed units, the mathmatics model in agreement with the integrated operation characteristics is proposed.
2) Output capability forecast of renewable energy power generation unit: Solar and wind power is random and intermittent, whose output is greatly affected by the environment. The effective and accurate method to predict solar and wind power in the short and long term is the basis of the economic optimization operation of the micro grid.
3) Micro grid dispatching strategy: Micro grid systems consist of renewable energy generation units, bi-directional energy exchanging between energy storage units. Different micro grid system operation methods, the electricity market and renewable energy policies will affect the dispatching of distributed power in micro grid. Micro grid energy management system can be determined by the local thermoelectric demands, interactive electricity prices, fuel consumption, power quality requirements, etc. At the same time, it’s also required the micro grid can achieve seamless smoothly connection between the grid-connected and grid-isolated operation modes, and its control strategy should be studied.
4) Economic optimization of micro grid system: For economic optimization dispatch of conventional power system, the main problems are the optimization of hydroelectric and thermal power units. In micro grid, optimal dispatching problem involves the optimization of the output of a variety of distribution systems. The economic model should be established for each distributed power, and by using the lowest production cost as the objective function to solve the optimization problems of micro grid system.
5) Optimization Algorithm. Economic optimization problem in general is multi-constrained, nonlinear problem, and there is no absolute way to get the optimal solution of this optimization problem. A variety of traditional optimization algorithms and intelligent algorithms latest developments also have their own characteristics, but the convergence characteristics of the algorithms, search performance and parameter settings are still

requires further study. How to find a suitable algorithm that can take into account the convergence speed and quality is the key to solve the optimization problem.

Micro grid energy management system consists of three parts: distributed energy management systems, smart micro grid energy management center and the unit energy controllers, etc., among which the distributed energy management system is mainly responsible for managing the energy exchange between the micro grid systems and the external grid, and also its information exchange with the dispatch center; micro network intelligent energy management is the core of micro grid energy management system, by using the information provided by the distributed energy management system and unit energy controller, selecting the appropriate algorithm to achieve the management of the distributed generation units, storage units and the external network, and realise the energy balance and economical operation in micro grid; unit energy controller is responsible for all distributed micro grid units, including data collection and monitoring, renewable energy output forecast and the information exchange between storage units, power units and energy conversion unit.

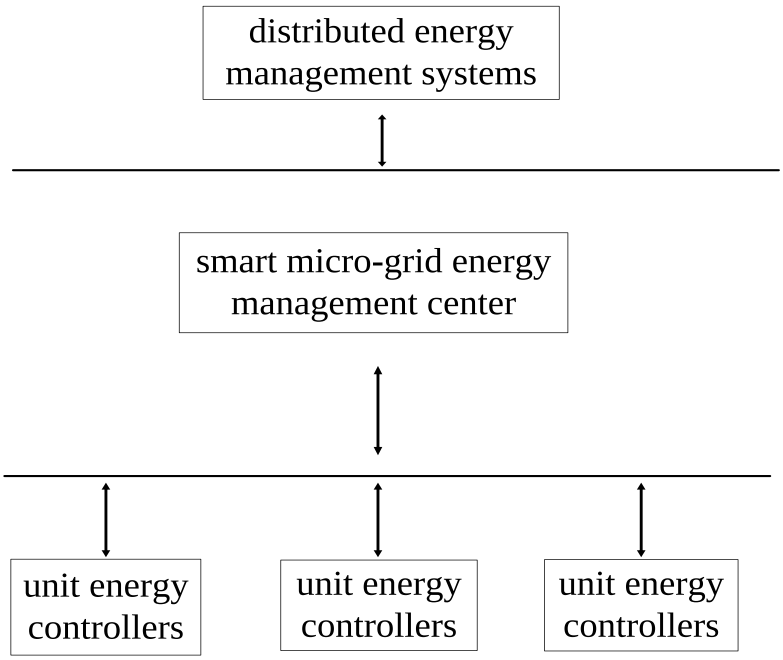

Figure 4-1 micro-grid energy management system structure diagram

The energy management system analyzes the distributed power, energy storage unit and load through the data acquisition, real-time monitoring and data exchange methods, and then evaluating their operational status. By entering the forecast data and the current data, choose a different energy management strategy according to different operating mode of micro grid, considering the cost of distributed power generation, environmental pollution costs, and the performance of the energy storage unit, the use of efficient algorithms for solving the future optimal operation plan for micro grid is adopted.

Specific functions of distributed energy management system are: micro grid load forcasting based on historical data, mainly indicating the data of short-term and ultra-short-term load forecasting, exchange real-time pricing with the dispatching center of the power marcket, power generation costs, operating mode, etc.. After obtaining the new data, it will feedback to the dispatch center by using the estimation results and price bidding program, finally the supply the energy based on the management center. Specific features of the smart micro grid energy management center are:

1) Accept the unit energy output of the renewable power and the remaining battery capacity data provided by the unit energy controller.
2) Receive load forecast and electricity cost data provided by the distributed energy management system.
3) Integrated micro grid distributed power storage information. In the condition of satisfying the conditions, minimize the power generation cost by proper optimization strategy, and send the strategy results to each unit controller and distributed energy management system, then performed by the control center.

The main function of the unit controller are:

1) Data collection and monitoring, including the meteorological data of renewable energy unit and the battery current and voltage.
2) For renewable energy, based on historical data and meteorological data to forecast the energy output of renewable energy, including long-term, medium-term, short-term and ultra short-term forecast of unit power generating output, and continuously improve the accuracy of forecasting models to enhance micro grid system reliability.
3) For the storage unit, real-time monitoring of battery voltage and current, in order to predict and manage the battery capacity.
4) for the electric car, coordinating with the battery management system, detect the battery state, and manage and control the sub-battery module.

5) Accept the dispatching plan from micro grid smart energy management center, and manage the output as plan.

4.2 Microgrid Operation and Management Strategies

Micro grid can run grid connected with external power grid, and it can also be isolated network operation, which has different target for energy management system, so as for the different strategy[50].

Management strategies of the Isolated Network Operation are:

1) Since the wind and photovoltaic power generation are random and intermittent , their output cannot be predicted precisely, and as a renewable energy, neither consume fuel nor pollution, it can output in priority.
2) When micro-power generating capacity can not meet all of the electrical load demands, and the remaining capacity of the energy storage unit is higher than the set capacity, prior consider the output from the discharge of the energy storage element to meet the load demand; when the remaining capacity of the storage unit is below the set value, open the more expensive distributed generation units to guarantee load demand.
3) When the micro grid system generation is similar with load demand, if the residule energy of the power storage unit is low, the storage unit can be charged first; if the energy storage unit is higher than the set capacity, turn off some of the expensive power unit. Use the energy storage devices to meet the energy balance system.
4) If the power generation unit is full capacity operation, and also the fully discharge of battery unit can not meet the load requirements, consider the shedding of part of the load, to ensure the power supply of the critical loads.

In grid connected mode, the micro grid is connected to the external grid, and the external grid can deliver power to the micro grid system in pursuit of economic operation. When the power quality of the micro grid satisfies the standards, the power exchange between micro grid and grid energy is permitted. Therefore energy management strategy in grid connected mode are:

1) Withdrawing power from the main network, but deliver power to the main network: the compare the electricity price of the distributed power grid and the power grid at

each time period, if the price of micro grid is higher, distributed power is turned off; if the micro grid electricity price is lower, start as usual. Associated with the use of a storage unit, adjust the operating condition of the storage system according to the electricity price.

2) When micro network can exchange electricity with the power grid freely: the operation strategy is almost the same above, except that: when the price of power grid is lower, micro grid absorbs as much power from the grid, both to meet the electricity load demand, also can charge the storage; when electricity price of grid in higher, the grid can absorb power from micro grid, battery discharge to obtain economic benefits.

4.3 Economic model of each element in micro grid

This thesis constructs a micro grid including various distributed power and electric vehicles microcell mobility storage system study, both wind power, photovoltaic, which are random-source output fluctuations, including micro gas turbine, etc., may adjust its stable output of controlled-source, as well as electric vehicles energy storage power station can be represented by the prediction unit, consisting of system architecture shown in Figura 4-2.

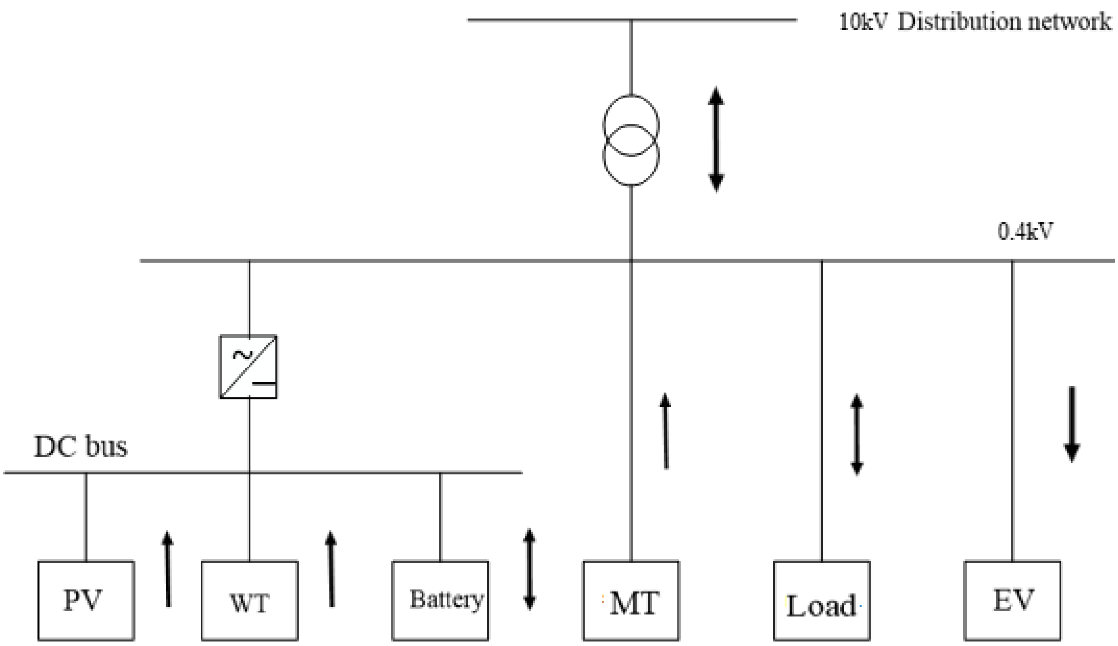

Figure 4-2 Micro network diagram constituted by the distributed power

Micro grid system for electricity generation unit and an energy storage unit characteristics analysis and establish appropriate energy management model is the basis for research and analysis. The modeling analysis below were respectively generating units and energy storage units.

4.3.1 PV Output Model

When PV (Photovoltaic, PV) units are series or parallel connected to form the photovoltaic modules, if the number of series cells is m, parallel cell number is n, the output power of PV modules are:

$$P_{PV} = mV \times nI \tag{4.1}$$

Where V is the output voltage of the photovoltaic cell (V); I is the output current of the PV(A).

In engineering application, this steady-state power output of PV modules use the following model. When solar radiation intensity, ambient temperature is different, the output of photovoltaic cells is different, so usually the photovoltaic power output will be converted under standard test conditions (solar irradiation intensity of 1000W/m^2, cell temperature is 25 ℃) , which can be expressed as:

$$P_{PV} = P_{STC} \frac{G_{ING}}{G_{STC}} [1 + k_{PV}(T_c - T_r)] \tag{4.2}$$

Where P_{PV} is the actual power output of PV modules (kW); G_{ING}, G_{STC} is the solar radiation intensity under actual and standard conditions (W/m^2), respectively; P_{STC} is the maximum output power under standard test conditions of PV module (kW); T_c is the battery temperature (℃); T_r is the reference temperature, T_r = 301.18K.

In fact, the output power efficiency should also be considered, because efficiency of power electronic converters, network losses and equipment aging will affect the efficiency of photovoltaic power generation system. At the same time, the PV array installation azimuth and angle, spacing, ventilation and cooling capacity will also affect the output efficiency, which is a factor to be considerd in the calculation of PV system output.

4.3.2 Wind Power Output Model

Wind (Wind Turbine, WT) output and wind speed are closely related, in practical system, when the wind speed is less than the cut-in speed, the output power of the wind turbine is zero; when the wind speed is greater than the cut-in speed and less than the rated wind speed, the relationship between wind power output and wind speed have determined a curve; when the wind speed is greater than the rated wind speed and less than the cut-out wind speed, the wind power output is the rated power; when the wind speed is greater than the cut-out wind speed, in order to prevent a security fails of the fans, the system will shut down. Formulated as:

$$P(v) = \begin{cases} 0 & 0 \le V < V_i \\ aV^2 + bV + c & V_i \le V < V_r \\ P_r & V_r \le V < V_e \\ 0 & V > V_e \end{cases} \tag{4.3}$$

Where $P(v)$, P_r are the wind turbine output power (kW) and rated power (kW); V is the actual wind speed (m / s); V_i is the cut-in wind speed (m / s); V_r is the rated wind speed (m / s); V_e is the cut out wind speed (m / s). Since the photovoltaic and wind turbine output is random and not controllable in the model, we use a variety of means to predict solar and wind power output.

4.3.3 Microturbine Model

Microturbine (Microturbine, MT) can also provide users with thermal energy while producing energy and collecting waste heat recovery system. It improves energy efficiency with good economic and social benefits. Gas turbine cogeneration includes "Power determined by heat" and "heat determined by power" two operation modes[50]. " Power determined by heat " generally refers to a system to meet the priority needs of the heating load, energy is seen as incidental items. If not meet the load demand, supplement will be made by power grid; " heat determined by power " approach refers to a system to meet the power load demand, incidental heat. Insufficient heat will be resolved by the afterburner.

Microturbine generating cost is related to the capacity and its power generation efficiency, as shown below:

$$C_{MT} = \frac{C_{nl}}{L}\sum_{j=1}^{J}\frac{P_j}{\eta_j} \tag{4.4}$$

Where P_J is a net energy(kWh) output during interval J; η_J is the efficiency during interval J; L is the low calorific value of natural gas, 9.7kWh/m^3. C_{nl} is Natural gas price, taken as 2.05 yuan / m^3 (yuan is the unit measurement of China's currency, nearly 7 yuan equals to 1 euro).

For certain types of gas turbine cogeneration system, the ratio of heat and electricity producted is a certain value, which is the rated thermal power ratio of the generation system. Formulated as follows:

$$\theta = \frac{Q_h}{Q_e}\times 100\% \tag{4.5}$$

Where θ is the thermoelectric output ratio; Q_h is the heat of the gas turbine cogeneration systems; Q_e is the energy electricity supply of the gas turbine cogeneration systems.

4.3.4 Battery Model

The battery in the micro network system can be used to stabilize the load fluctuations, conduct load shifting[51]. They can make the system give out stable power output, enhancing renewable energy generation schedulability with the cooperation of wind power, solar and other renewable energy generation technologies. Currently on the market there are lead-acid batteries, sodium sulfur batteries, lithium ion batteries and also all vanadium batteries. These batteries have some common characteristics. They can both charge and discharge, when there is insufficient remaining power, battery discharge; when the remaining have excess power generation, battery charging. But they have a limited capacity. The battery capacity of time t has relationship with the previous period t-1, battery capacity information may be represented by the following formula:

$$\text{Charging State: } S_{bat\_t} = S_{bat\_t-1} - P_{dis\_t} \tag{4.6}$$

$$\text{Discharging State: } S_{bat\_t} = S_{bat\_t-1} + P_{cha\_t} \tag{4.7}$$

$$\text{with } S_{\min} \le S_{bat\_t} \le S_{\max} \tag{4.8}$$

Where S_{bat_t}, S_{bat_t-1} is the battery capacity at time t and t-1, respectively(Wh); $P_{dis}(t)$, $P_{cha}(t)$ are the charge and discharge capacity of time t; $S_{\min}$, $S_{\max}$ are the minimum and maximum battery storage, respectively. This thesis don't consider the battery charge and discharge efficiency for the reason of simplicity.

4.3.5 EV Energy Storage Power Station Model

Electric vehicle charging behavior is influenced by both battery characteristics and user behavior, mainly because uncertainty of the charging time and charging space. However, accessed to the micro grid, electric vehicles, on one hand naturally divided the activity area of the owners , so that all the behaviors converge in space, on the other hand, on the premise of fullfil the owners' demand, coordination charging for smoothing out fluctuations of distributed power in the micro network. On the basis of improving load curve, take full use of cheap electricity at night, save output microturbine and other controlled-source and realize the real economy operation of microgrid[52].

As mentioned before, there are two charging ways for electric car, plug mode and swap mode. This thesis considers the function of V2G power reversely sending back to grid and adopt the swap charging mode to connect to the grid. As shown in chapter 3.2.2, by the findings of the US Department of Transportation vehicles across the United States, namely the last time a private vehicle return to their garage and the probability distribution of the daily mileage statistics. By estimating the electric vehicle charging load, you can get electric cars charging load expectations.

Analyzing according to the assumption of the electric car in part 3.3, electric car station models can be expressed as follows:

$$|P_{nk}| \le P_{nkm} \tag{4.9}$$

$$Q_n = Q_{n-1} + P_n \Delta t - E_n \tag{4.10}$$

$$Q_{n\min} \le Q_n \le Q_{n\max} \tag{4.11}$$

Where P_{nk} is the charge and discharge power of kth electric vehicle. Positive means charging and negative means discharging. P_{nkm} is the upper limitation of charge and discharge power, determined by the largest charge and discharge power, the capacity of distribution transformer and other co-decision. Q_n is the energy electricity stored in power station in time n. Assuming that the number of battery in the swap station is dynamic equilibrium, namely although there are import and outport, the number is the same. And the electric car battery discharge depth is controlled more than 20%.

$$E_n = \sum_{k=1}^{m} (E_{enk} - E_{snk}) \tag{4.12}$$

$$E_n = (1-40\%)Q_n * M * E_p \tag{4.13}$$

E_n stands for electricity demand of electric vehicles at one time. E_e and E_s are the electricity in vehicle when user reach and leave the power palnts. When the vehicle is assumed to return to the power plants with the remaining electricity obey the normal distribution with expectation of 40%. It can be calculated by multiplying the number of vehicles and the total quantity of exchanging power.

4.4 Economic Model of System in Micro Grid

Economic optimal operation of microgrids is to guide the scheduling of micro-network unit output by minimizing operating costs. Solution to this problem is based on forecast data of photovoltaic, wind power and electric load already known. Considering a slight difference in the micro network islanding and grid connected operation, we consider micro gas turbine output, exchange power from the grid, energy storage inputs and electric vehicles coordinating scheduling to determine the optimal solution. This topic combines the micro grid elements model and the specific problems of electric car grid access solutions. Focus on the design of micro grid system economic model with electric vehicle energy storage power station, dividing the total cost from input costs, operating costs and risk costs, building the objective function and constraints of micro grid system operation

4.4.1 Cost Analysis

During the running of Micro grid systems, different devices have a variety of consumption and costs, such as fuel costs, purchase costs, loss costs, maintenance and management costs.

The size of the storage capacity determins the economy and the micro network optimization strategies. This thesis will take into account the storage of input costs, combining the research on battery life and cost of the battery in chapter 3.2 to convert the inputs into the daily cost loss. In addition, taking into account the wind load overflow and load shedding risk cost, based on full consideration of these factors, analyze the economic operation of grid scheduling.

1) Storage investment cost

Energy storage technology is widely used in the power system. They play an important role in eletrical peak-shaving, improving system stability, and power quality assurance. In daily operation, the micro grid, influenced by the environment, wind power and photovoltaic power distribution generation might not work. Super capacitor, flywheel and other distributed energy storage device, may play a role in the transition at this time , continue to provide users with electricity; by the control of energy storage device, the system disturbance will be stabilized; it will also provide emergency power to support, improve power quality and maintain stability of the system, what’s more, access economic benefits by storing electricity.

The effect of Micro grid energy storage system embody in the following two ways: when the system transmission power coming form the grid is greater than the load demand, the excess energy will be stored; when the system supply and demand become imbalanced, it will rapidly release energy. Thus, the energy storage device within the system is good for energy regulation and control, good for more efficient and rational use of energy. When the primary network fails, the supply and demand imbalance will lead the system voltage drop and load instability, which will lead to severe load shedding. Temporary use of distributed energy storage technology in a short time and quickly provide the required power balance system, it will support volatege and ensure the operation of the load. Acting as short source in short-term emergency control, the storage will reduce the impact to micro grid in the greatest degree.

Battery energy storage can be used as stand-alone power applications in power plants, substations, communication system, and other relay protection devices to supply power; and may assist reactive power compensation device (STATCOM), to improve its dynamic performance and suppress low frequency oscillation. Today, battery energy storage has been widely used because of its simple structure, small space ocupied, easy to install near the load center, and the ability to compensate for cyclical effectively. Battery energy storage system can be connected to the grid power to compensate, which will significantly improve power quality. However, due to the short life, environmental pollution and many other issues, the application gets limited.

Table 4-1 shows performance parameters of several storage[53]. Battery technology is mature, the power density of super capacity is much lower than flywheel. The effect of fast compensation will be worse, while the supercapacitors have higher cost. We use battery which have more mature technology to serve as the energy storage device.

Table 4-1 Performance parameters of several storage

Storage	Energy density $/kJ \cdot L^{-1}$	Power density $/kW \cdot L^{-1}$	Efficiency	Energy cost/ dollar $\cdot(kW \cdot h)^{-1}$	Power cost/ dollar $\cdot kW^{-1}$	Life/a
Lead-acid	3.0~4.8	0.01~0.40	0.85	300~600	200~400	5~10
Redox flow	0.96~1.98		0.70~0.85	600~1500	150~1000	5~10
Sodium sulfide	9~15		0.75~0.86	1000~3000	300~500	10~15
Super capacity	0.6~1.8	100	0.95	100~300	300~2600	20
Fly wheel	1.2~4.8	1~2	0.90	250~350	1000~5000	15

After determining the type of stored energy, we need to analyze the input costs of energy storage. The storage capacity includes both power and energy input, which corresponds to the cost of power and energy cost, as shown in the following equation.

$$\sum_{m}^{M} \frac{C_{esm} * E_{sm\max} + C_{psm} * P_{sm\max}}{Lifetime} \tag{4.14}$$

Where m represents energy storage category, E_{sm} and P_{sm} represents m class storage capacity and power, C_{esm}, C_{psm}, represents storage capacity per unit cost and power per unit cost . The unit time is count in hours. Uaually, calculate the storage output in each scheduling period through optimization program so that the maximum E_{smmax} is the storage capacity of m class we should put in, similarly the maximum power P_{smmax}. Here storage charging and discharging power are expressed by P_{sm}, when a positive value on behalf of discharge, while a negative value on behalf of the charge.

The above is the one-time cost of inputs considered for storage costs and power costs, due to the dimension of the optimization model is based on the entire 24-hour period, so we can take advantage of research on the storage life of 3.2, namely using rain flow algorithm to calculate the energy storage lifetim. According to their life-time investment, costs will be converted to everyday, thus ensuring the consistent in time dimension.

2) Operation cost

Operation costs includes the cost of running various types of distribution generation, including operating and maintenance costs, fuel costs and pollution cure costs. Because wind and solar energy make use of natural resources, they have maintenance and operation costs but their fuel costs are not considered in the model.

(1) Operating and maintenance cost

Operating and maintenance cost are counted in every KWh. So it can be resented as the equation below:

$$C_{op} = \sum_{i=1}^{N} \sum_{t=1}^{24} P_{i\_t} C_{op,i} \tag{4.15}$$

Where C_{op} is the total Operating and maintenance cost in 24 hours; $C_{op,i}$ is the unit operating and maintennance costs of the ith distribution generation; P_{i_t} is the output of the ith distribution generation; N is the number of distributed generation.

(2) Fuel cost

For renewable energy, the generation costs can be considered as zero. For the fuel consumption of the power generation unit, the fuel cost of power generation can be defined as the cost of fuel per unit multiplied by the desired energy. Therefore, the fuel cost can be expressed as:

$$C_{fu} = \sum_{i=1}^{L} \sum_{t=1}^{24} E_{i\_t} C_i \tag{4.16}$$

Where E_{i_t} is the electricity consumed in time i; C_i is the cost equation of fuel generator, usually the function of E_{i_t}; L is the number of fuel generator.

(3) Pollution cost

During the operation of Micro grid, the pollution from the process should be controlled to increase environment benefit.

$$C_{po} = \sum_{l=1}^{L} 10^{-3} \beta_l \sum_{i=1}^{N} \alpha_{il} P_{it} \tag{4.17}$$

Where C_{po} is the total cost for curing the pollution; L is the number of pollutants; β_l is the cost coefficient of pollutant l (Yuan/kg); α_{il} is the coefficient of pollution by different mode of production (g/kWh); P_{it} is the unit power.

3) Risk cost

From the green economy and practical aspects to consider, we introduce penalty term risk. For the power beyond the risk part, we bring in the risk costs to ensure microgrid load supply reliability and efficiency.

Risk costs include two parts, load shedding and new energy wind power, photovoltaic output power overflow. As the micro grid and distribution network can exchange power randomly without any limitation in the grid connected operation strategy. There is no meaning consider the risk at this time. So, we just consider the risk in the isolated island and fixed exchanging power mode.

Wind and PV overflow: there is a regulation that all the power produced by WT or PV can be used sufficiently, even if there is too much, the rest of the power can be absorbed in the storage, which will help not lead to the wind and light waste. It can be present as below:

$P_w+P_p-(P_L-P_G-P_{MT})-P_s-P_{EV}$ namely, $P_{MT}+P_G-P_L+P_w+P_p-P_s-P_{EV}$（charge）

Load shedding: The output power can meet all the load. No possible that there is load shedding after the battery discharging to the end.

$P_L-(P_w+P_p+P_s+P_{EV}+P_G+P_{MT})$ namely, $-(P_{MT}+P_G-P_L+P_w+P_p+P_s+P_{EV})$(discharge)

Unify these two items,we can express othe risk cost as follows:

$$\sum_{t=1}^{24} [(K_p \left| P_G - (P_{Lt} - P_{wt} - P_{pt} - P_{st} - P_{EV} - P_{MT}) \right|] \tag{4.18}$$

Where P_G is the exchange power between micro grid and distribution grid,P_{MT} is the micro turbine output, P_w is the WT output, P_P is the PV output, P_L is the load power, P_s is the storage output, positive means discharging and negative means charging. *k* is the time. K_p is the risk proportion, in order to reflect the proportion of risk in the whole system.

4) Exchanging power from the distribution grid

The exchanging power is the power transported from micro grid and distrbution grid. In the period of 24 hours, the cost is like this:

$$C_{jh} = \sum_{t=1}^{24} C_{price\_t} P_{jh\_t} \tag{4.19}$$

Where C_{price_t} is the price for time t, P_{jh_t} is the exchange power in time t. It will be positive if the power is flow to the micro grid and negative vice versa.

4.4.2 Objective Function

We will consider three strategies operation in this thesis, different objective functions are listed as below.

1) Isolated island operation mode

When the micro grid is isolated island operating, the connection with the big grid is cut off. The objective function with the target of minimize the cost in 24 hours can be shown as:

$$\begin{aligned} Cost = {} & \frac{C_{ES} E_{Smax} + C_{PS} P_{Smax}}{Lifetime} + \sum_{MT} C_i(P_{i\_t}) + \sum_{MT} (\lambda_{CO_2} + \lambda_{SO_2} + \lambda_{NO_X}) P_{i\_t} \\ & + \sum_{MT,WT,PV} K_{OM} P_{i\_t} + \sum_{t=1}^{24} [K_p | P_{Lt} - P_{wt} - P_{pt} - P_{MT} - P_{st} - P_{EV}] \end{aligned} \tag{4.20}$$

There are three parts in the objective function: storage investment, operating cost for distribution generation and the risk cost. The left side of the equation is the total cost for 24 hours, WT, PV, MT stand for the wind turbine, photovoltaic and micro turbine. $C_i(P_{i\_t})$ is the generation fees for a resource. λ_{CO_2} , λ_{SO_2} , λ_{NO_x} are dioxide, sulfur dioxide and nitrogen oxides Emission control coefficient. K_{OMi} is the operating and maintence coefficient of the ith resource. P_{i_t} is the generation amount of resource in time t. K_p is the penalty coefficient. P_{Lt}, P_{wt}, P_{pt}, P_{MT}, P_{st}, P_{EV} are the power of load, WT, PV, MT, battery and EV.

2) Grid connected operation with constant exchanging power from big grid

Grid connected operation with constant exchanging power P_G is good for the control of micro grid. Although we use a constant value here in this thesis, but variable value can still be allowed to modify the value and optimize the reslut, such as piecewise constant or different time period constant.

In this occasion, there is a trade off between storage configuration and load, that is, althought the power is balanced all the time, the output of power do not have to be absorbed totally and there is also possibility for the load shedding. In this way, the risk (penalty cost) is existed. Objective function is as below, which is almost the same except for the cost of the exchange power.

$$Cost = \frac{C_{ES}E_{Smax}+C_{PS}P_{Smax}}{Lifetime} + \sum_{MT} C_i(P_i(t)) + \sum_{MT} (\lambda_{CO_2}+\lambda_{SO_2}+\lambda_{NO_X})P_i(t) + \sum_{MT,WT,PV} K_{OMi}P_i(t) + \sum_{t=1}^{24} [K_p|P_G - P_{Lt} + P_{wt} + P_{pt} + P_{MT} + P_{st} + P_{EV})] + C_{buy}(t)P_{buy}(t) \tag{4.21}$$

3) Grid connected operation with non-fixed exchanging power

When the micro grid is operating with umlimited exchange power, the balance is continious and without a restrict. So that the meaning of risk at this circumstance is not so big, because theoretically, the different power can be compensate by the exchange power in every condition. So, the objective function is like below:

$$Cost = \frac{C_{ES}E_{Smax}+C_{PS}P_{Smax}}{Lifetime} + \sum_{MT} C_i(P_i(t)) + \sum_{MT} (\lambda_{CO_2}+\lambda_{SO_2}+\lambda_{NO_X})P_i(t) + \sum_{MT,WT,PV} K_{OMi}P_i(t) + +C_{buy}(t)P_{buy}(t) \tag{4.22}$$

Where $C_{buy}(t)$ is the price micro grid purchasing from the distribution grid and $P_{buy}(t)$ is amount of power micro grid buys from the distribution grid.

4.4.3 Constraints

On the basis of element model and system model we analyzed above, we define the objective function based on the minimum cost, adding the physical condition to the mathematic system; we will list the equality and non-equality constraints in the section.

1) Power balance

$$P_{PV}(t)+P_{WT}(t)+P_{MT}(t)+P_s(t)+P_{buy}(t)=P_L(t)+P_{EV}(t)+P_{sell}(t) \tag{4.23}$$

Where $P_{PV}(t)$, $P_{WT}(t)$， $P_{MT}(t)$ represent the output power of PV,WT and MT; $P_s(t)$ is the charging and discharging power of battery; $P_{sell}(t)$ 、 $P_{buy}(t)$ are the buying and selling electricity respectively. $P_L(t)$ is the original load of micro grid in time t. $P_{EV}(t)$ is the electric vehicle charging load.

2) Storage capacity

$$E_{s1,k+1} = E_{s1,k} - P_{s1,k}\Delta t, k = 1, 2...N-1 \tag{4.24}$$

3) Storage DOD (depth of discharge)

$$0.2E_{s,\max} \le E_{s,k} \le 0.8E_{s,\max}, k = 1,2...N \tag{4.25}$$

As analysis in chapter 3, the depth of discharg and charging is among 20% to 80% for the reason of lifetime.

4) Discharging/charging power

$$|P_{sk}| \le P_{s\max}, \forall k = 1,2...N \tag{4.26}$$

Where P_{sk} is the charging power of the battery and P_{smax} is the charging and discharging limitation.

5) Turbine output

$$P_{MT.\min}(t) \le P_{MT}(t) \le P_{MT.\max}(t) \tag{4.27}$$

Where $P_{X.\min}(t)$, $P_{X.\max}(t)$ are the upper and lower generating limitation of distribution generation in time t.

6) Tie line power

$$P_{line.\min} \le P_{buy}(t) \le P_{line.\max} \tag{4.28}$$

$$P_{line.\min} \le P_{sell}(t) \le P_{line.\max} \tag{4.29}$$

Where $P_{line.\min}$, $P_{line.\max}$ is the upper and lower exchanging power limitation between micro grid and extranl grid. $P_{buy}(t)$ is the micro grid purchasing power and $P_{sell}(t)$ is the power selling to the distribution grid.

5 ANALYSIS OF ECONOMIC OPERATION OF MICRO GRID CONSIDERING EV ENERGY STORAGE SYSTEM

5.1 Basic Data

This thesis chooses an industrial district micro grid design. It builds a micro grid system connected with the common grid. The frame is shown as the figure 5-1. The micro grid include photovoltaic, wind turbine, micro turbine, battery and electric vehicle storage station, where the rated power of PV is 100kW, the rated power of WT and MT are the same, 200kW. Battery dispatching is what we should solve in the model. One EV storage station, three micro turbines, and other power sources are each for one.

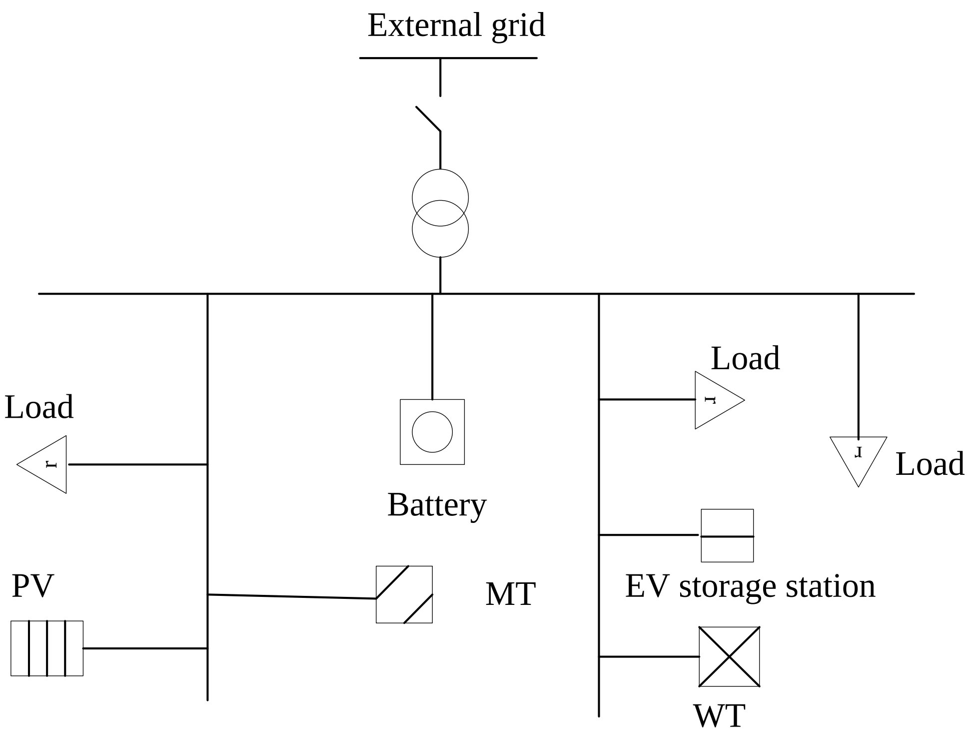

Figure 5-1 The structure of micro grid

Adopting the classic data in winter, referring to some reference, the output of WT, PV and forecasting of load are described in the figure below.

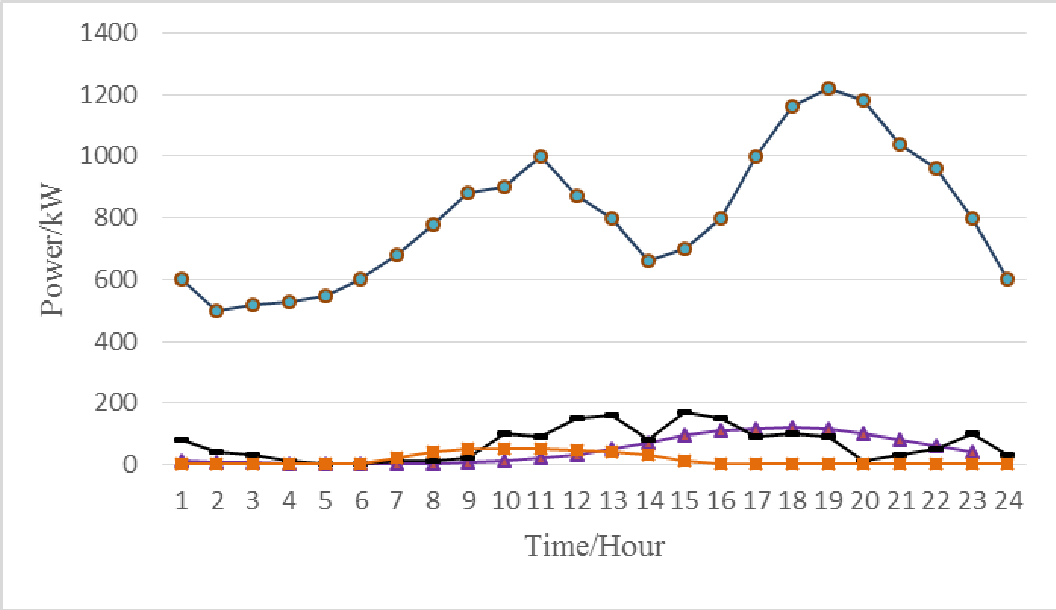

Figure 5-2 The output of WT, PV and Load forecasting

The scale and relevant parameter are the same as the case in chapter 3. There are 20 sets of charging device and EV battery. The charging power is 6 kW for each and 120kW for total. The capacity of the distribution transform is 2.2 MW, while the storage system of the EV is 65kWh. The charging energy electricity obey the normal distribution with the expectation of 40%.

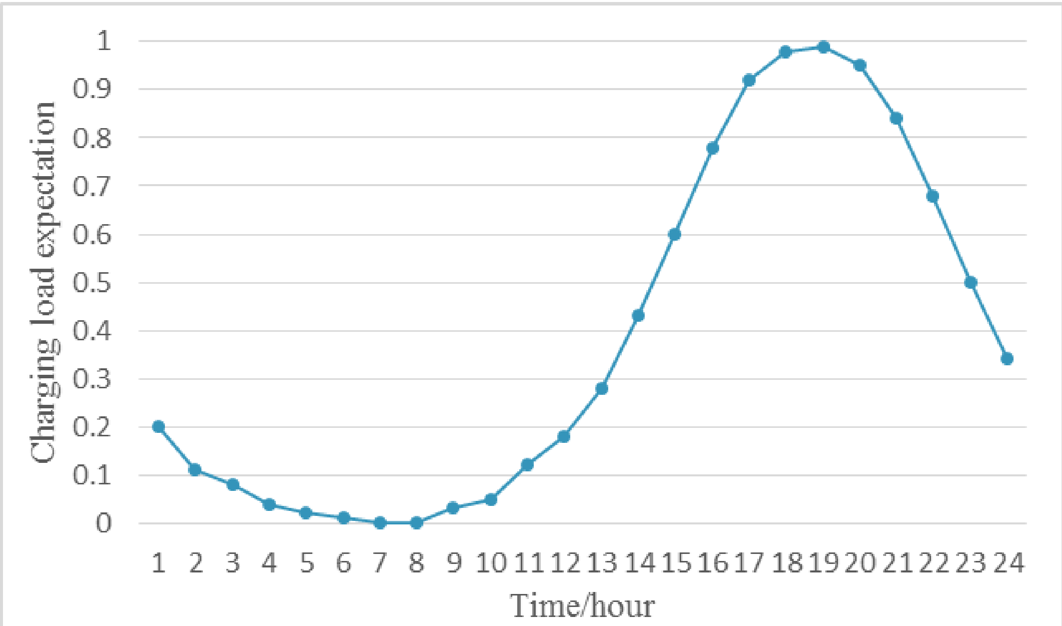

Figure 5-3 The expectation of the charging load

As the WT and PV are natural resources and are renewable energy, only the maintenance fees are considered in this thesis. The Micro turbine is 200 kW and the efficiency curve is like the figure 5-4.

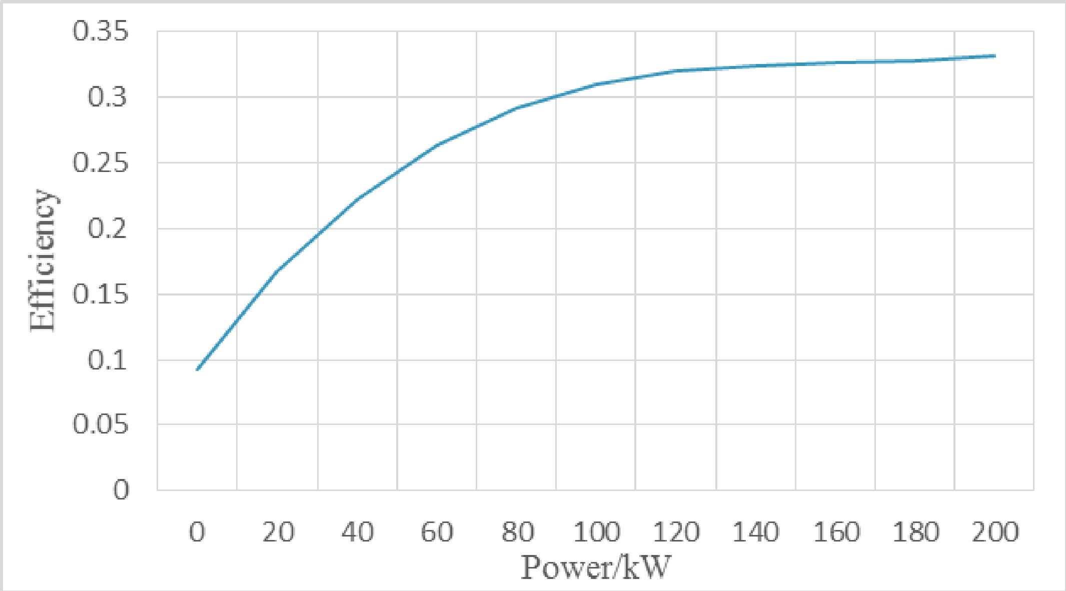

Figure 5-4 The efficiency-power curve of MT

The equation can be fit for one MT:

$$\eta = 0.4166(\frac{P}{200})^3 - 1.0135(\frac{P}{200})^2 + 0.8365(\frac{P}{200}) + 0.0926 \tag{5.1}$$

In a similar way，the efficiency-power curve of three MT

$$\eta = 0.4166(\frac{P}{600})^3 - 1.0135(\frac{P}{600})^2 + 0.8365(\frac{P}{600}) + 0.0926 \tag{5.2}$$

The waste gas emission factor of MT is like the table 5-1.

Table 5-1 The emission factor of waste gas：yuan/MWh

Emission factor	λ_{CO_2}	λ_{SO_2}	λ_{NO_x}
MT	1.6	0.0216	16.652

The unit energy maintenance fee of PV, WT and MT is described in the table 5-2:

Table 5-2 Operation maintenance cost coefficient of DG：yuan/kWh

DG	PV	WT	MT
Operation maintenance cost coefficient	0.0096	0.0296	0.047

Battery capacity is a part of investment and is the value we should calculate by the model. This thesis do not take into account the charging and discharging efficiency and using P_{sk} to indicate, positive means discharging and negative means charging.

The step price policy is implement in this thesis, as shown below. 11:00-15:0 and 19:00-21:00 are peak periods. Normal periods are 08:00-10:00, 16:00-18:00 and 22:00-23:00, while valley periods is 00:00-07:00.

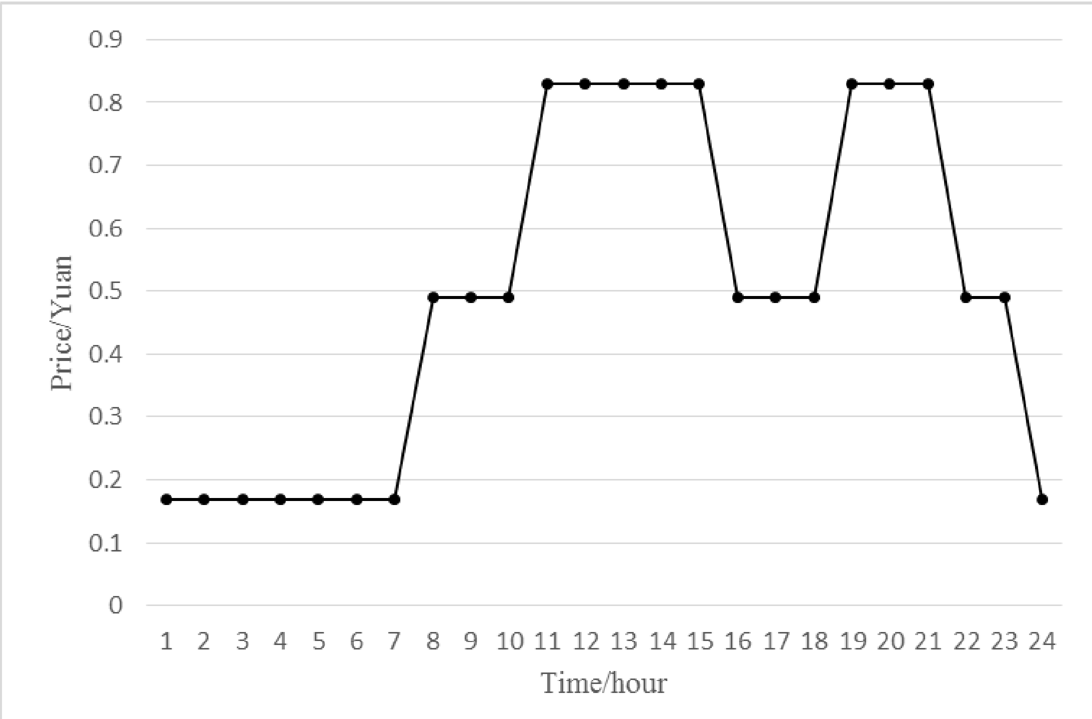

Figure 5-5 Electricity step price figure

(yuan is China's currency measurement unit, nearly 7 yuan equals to 1 euro)

Table 5-3 Electricity step price Yuan/kWh

Period	Peak	Normal	valley
Price for purchuase	1.66	0.98	0.34

5.2 The Economic Operation of Micro Grid with EV Random Charging

Since driving behavior and charging behavior of electric vehicle owners are nearly the same, non-fixed charging without coordination will bring the grid extra load pressure. This section does not consider scheduling coordination charging of electric vehicles, namely charging load in the case of natural distribution. We will analyze three operation modes: isolated grid, grid-connected with constant value and grid-connected with random value. The investment of storage is seen as a one-time investment cost and then converted to the corresponding costs based on life cycle costs.

5.2.1 Grid-connected with Non-fixed Exchange Power

Grid-connected with non-fixed exchange power means micro grid is operating connected with the distribution network by getting in or sending out power just constrainted by the power limitation of the connecting line. Because of the unlimited exchange power, the output of distribution generation and the load are balanced all the time, as shown in the equation below, where the P_{line} stands for the exchange power between distribution grid and micro grid. When it buy electricity from the grid, P_{line} is positive, while when it sells electricity to the grid, P_{line} is negative. Except for the power balance, load shedding and the overflow of WT and PV do not exist. There is no need to consider it.

$$P_{PV}(t)+P_{WT}(t)+P_{MT}(t)+P_{s}(t)+P_{line}(t)=P_{L}(t)+P_{EV}(t) \tag{5.3}$$

Making use of the model built in chapter 4 and then make simulation by programming in CPLEX. As a result of three C200 micro turbines in the system, MT contribute a maximum of 600kW. We set the P_{line} up to 300kW. Making use of various algorithms in CPLEX, such as linear programming and mixed integer programming, we can get the contribution of all the elements in micro grid. Figure 5-6 shows the micro turbine power output and the size of the exchange power.

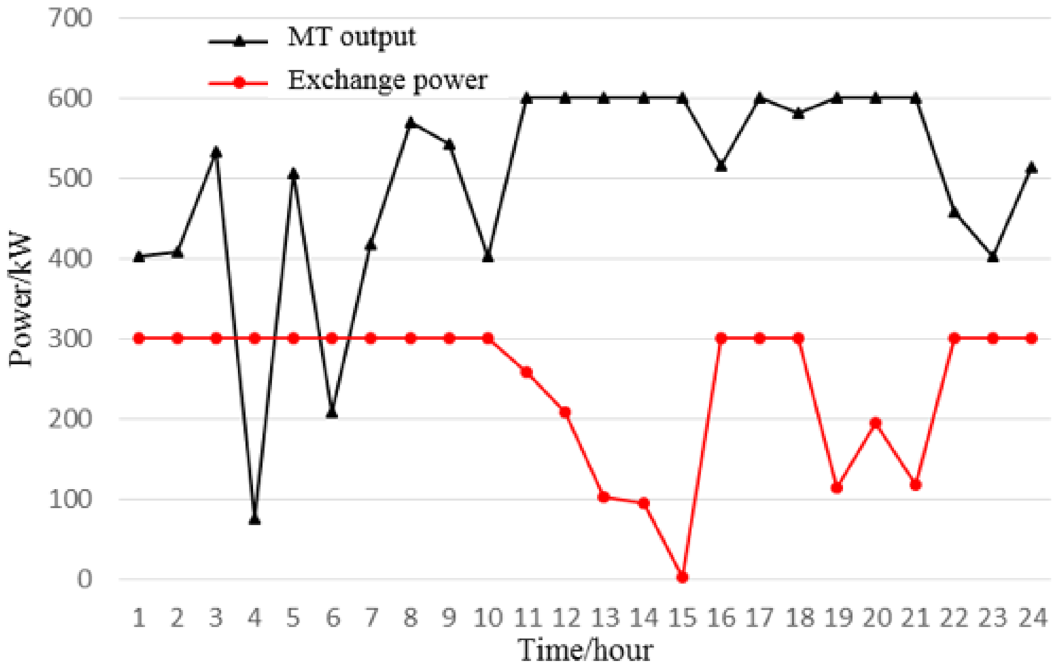

Figure 5-6 Curve of output of MT and exchange power in grid-connected operation

As can be seen from Figure 5-6, in periods of 1: 00-10: 00, 16: 00-18: 00, and 22: 00-24: 00, the exchange power are reaching to the maximum, which means try to buy as much as electricity from the big grid. Combining the step price of electricity, all these three periods are normal price or valley price. But in the period of 11: 00-15: 00 and 19: 00-22:00, due to the price rise, it has been not the best choice to buy electricity from the grid, but by through the full work of micro turbine to meet load power requirements. As a whole, the performance of exchange power curve is consistent with price curve. By analyzing the comparison between micro turbine cost and the price curve, we can illustrate the optimization results in a better way.

Figure 5-7 is the comparison of DG electricity generation costs with step price. The overall cost of MT electricity generation can be seen: it is higher than usual normal price and valley price, while lower than the peak price when the output is above 180kW, which provide the possibility for coordinate dispatching for micro grid. Figure 5-6 also shows that in 11: 00-15: 00 and 19: 00-20: 00 two peak load periods, the MT works at the maximum point. What's more, when the output of MT is lower than 120kW, due to the start-up costs and other factors, the electricity generation cost is high. So, the input of micro turbine at 100kW or less is not economical. That's why micro turbine is more used for higher power output.

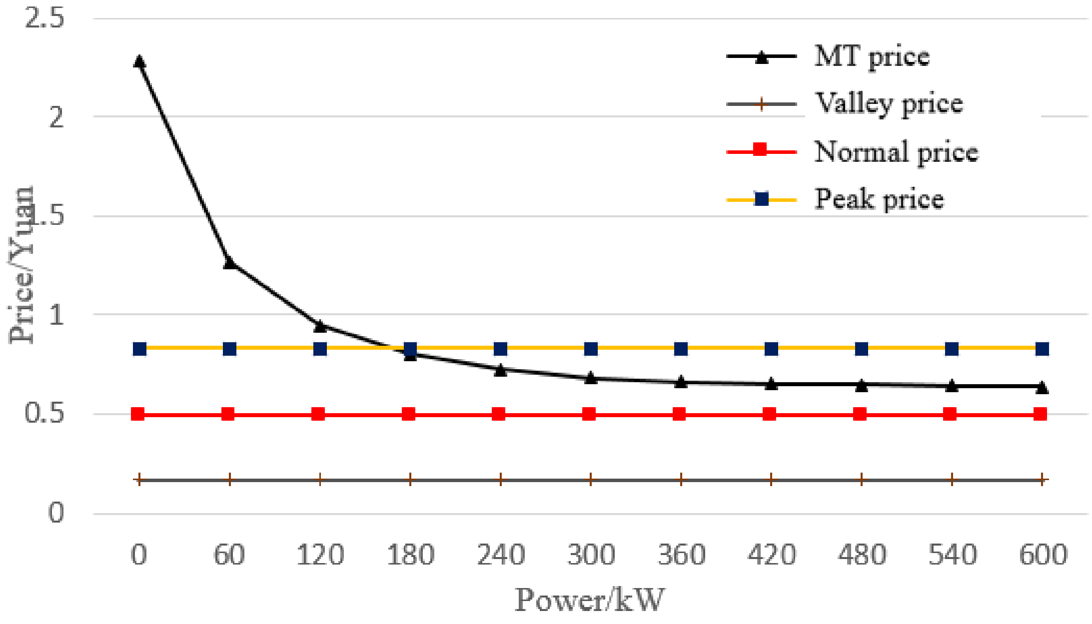

Figure 5-7 The comparison of step price and MT electricity generate cost

In the operation mode of grid-connected with non-fixed exchange power, the micro grid system has the storage configuration: E_{smax} is 2388.7 kWh and P_{smax} is 384kW. Operation cost: $Cost = 8858.2+7573.7+2507.1+685.24=19624.24$ yuan.(yuan is china's currency measurement unit, 7 yuan equals to 1euro)

5.2.2 Grid-connected with Constant Exchange Power

Grid-connected with constant exchange power is to consider from the point of view that micro grid is a single controllable element. By setting the exchange power in the connecting line, the grid can achieve to control this unified network. By introducing the risk, we can use penalty fees to constrain when there is a load shedding or WT and PV overflow, which represent the unbalanced power, as the equation below. This will help improve the utilization efficiency of DG and the reliability of load supply. According to the objective function in the chapter 4, in the operation mode of grid-connected with constant exchange power, all the micro grid cost are divided into 4 parts, the storage investment, the operation cost of micro grid, the risk cost of penalty and the exchange power with distribution grid.

Since the distribution network and micro grid power transmission setting is not easy to control, we use the most simple power transmission setting to achieve the effect of qualitative research. We set the exchange power as 0.8 times the average value of original load (P_l: the load in the industrial district), charging load (P_{EV}:electric vehicle need to be charged), wind turbine output P_w and PV output P_p, as the equation below.

$$P_{line} = 0.8 * \frac{1}{24} * \sum_{1}^{N} (P_l + P_{EV} - P_w - P_p) = 6910kW \tag{5.4}$$

Figure 5-9 shows the MT output, battery charge and discharge power and exchange power curve in this operation mode. For the battery output power, positive means discharging while negative means charging. Because the exchange power is constant, the common output of MT and battery work together to contribute to meet the load demand. During 1: 00-6: 00, the load power is small, and therefore MT do not contribute in the beginning. The load can be supplied rely only on the constant transmission power and the battery discharge power. Together with the increase of load curve, MT maintain full power output over a long period of time. In addition to supply the load, the excess power is used to charge the battery.

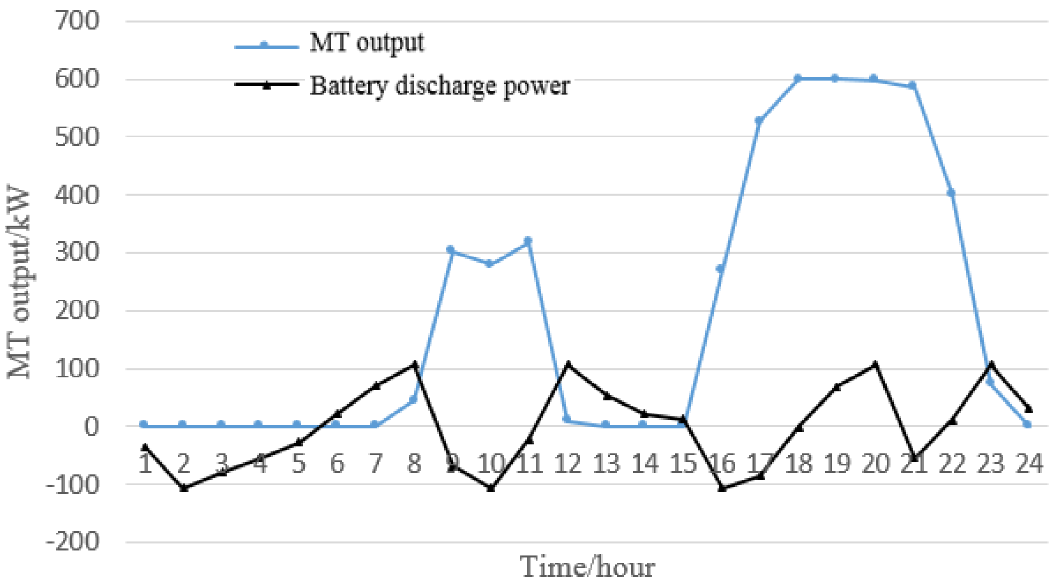

Figure 5-8 MT output, batterydischarging power and exchange power

As can be seen from the figure, in the peak load of 8: 00-12: 00 and 19: 00-22: 00, MT reaches maximum output in order to meet the original load and charging load demand with exchange power, while the battery is charging in this period shown in figure 5- 8, 5-9. When the electric vehicle is charging without coordination, the charging load which is naturally distributed will add to the peak load of micro grid. The system has to buy more electricity from the distribution network to meet the needs of the moment. When the exchange power is small, the required storage capacity requires a very large configuration to ensure that the imbalanced power is controlled in a certain range, which is not conducive to the economic operation of micro grid. Later we will optimize dispatching the charging load to reduce the storage investment costs.

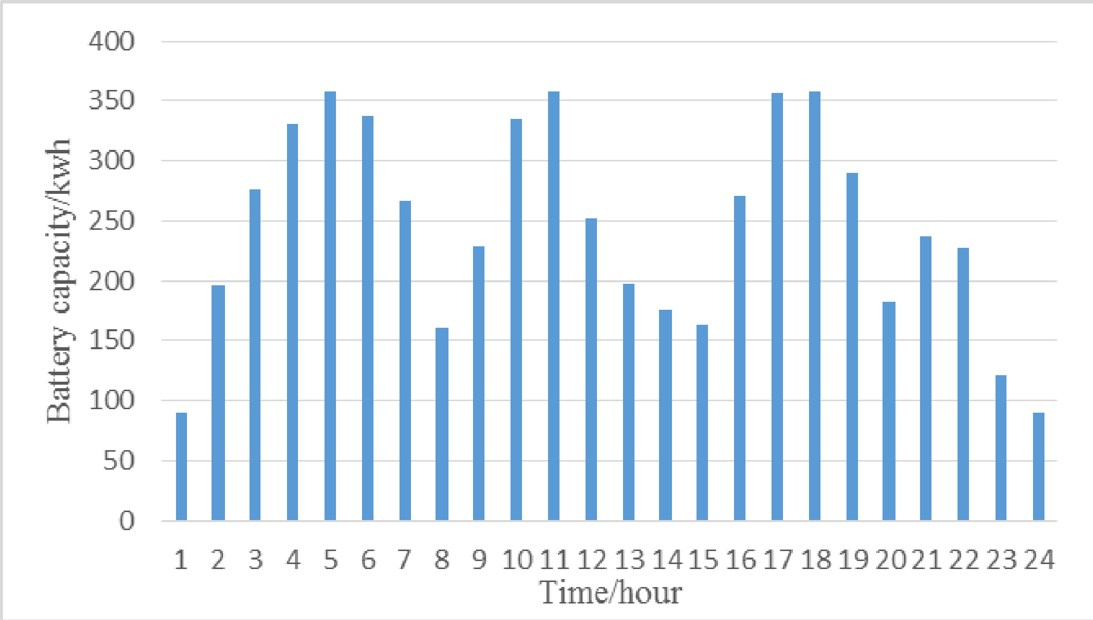

Figure 5-9 The battery capacity of grid connected with constant exchange power

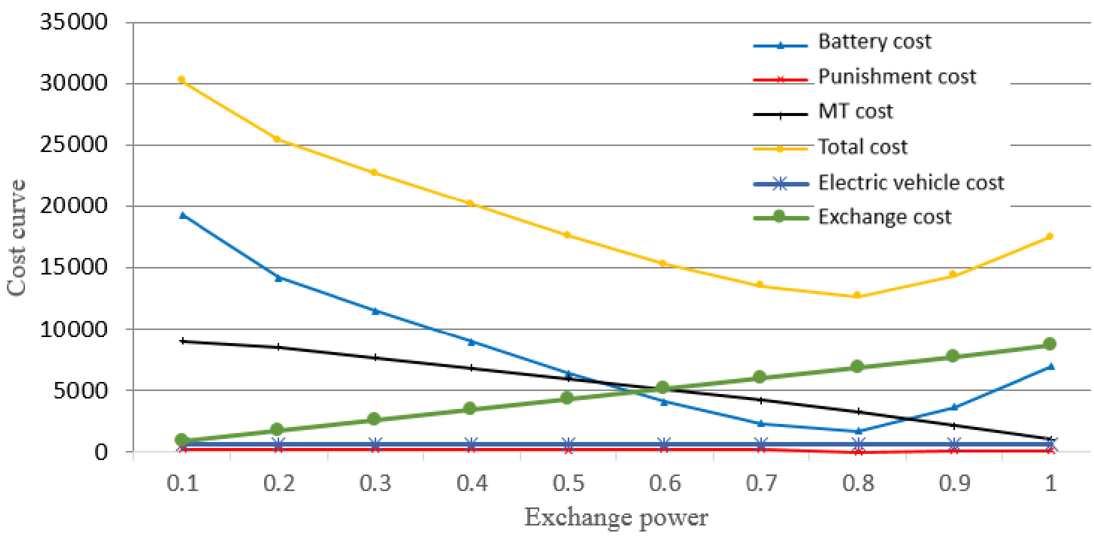

Figure 5-10 The cost curve of different parts with the change of exchange power

From the point of view that seeing the micro grid as a single controllable element, the grid connected with constant exchanging power is designed in this way to give a clear forecast. While the setting of exchange power is influenced by a lot of factors, we handle it in a simple way in this thesis, and can make some improvements in the following steps. Figure

5-10shows the cost of different parts changing curve with the changing of exchange power. The exchange is based on the average value of variable elements in the micro grid and given in per unit quantity.

As shown in Figure 5-10, with the changes of exchange power, the total cost consists of five micro grid operating costs would also change. Overall, the micro gas turbine output increases with the decreasement exchange power, namely the more electricity micro grid buy from the distribution network, the lighter micro turbine will undertake. Penalty cost, MT output and battery output are present as a "V" shape. When the exchange power is small, the power supply has greater uncertainty. Although the micro gas turbine and batteries can work to give out, but its reliability and economy are not as good as to buy directly from the power grid. The penalty fee is reduced to 0 when the exchange power is 0.8 times benchmark value, which indicate that from the point of view of economic, it is an ideal operation status without load shedding and wind or light overflow are zero. As the exchange power goes higher, the penalty part arises again because the adjustment flexibility is reduced due to the bringing in of constant value.

The battery cost meets the minimum value also at the 0.8 times benchmark. This is also because when the exchange power is small, there needs big amount of storage input to insure the load supply. When it increases, battery input becomes lower, while it begin to rise when the exchange power continue increasing. This is because the supply is just a straight line that more storage should be invested to adjust.

Overall, batteries, micro gas turbine and exchange electricity costs determine the trend of the total cost together. Micro gas turbine and exchange electricity cost increases becomes monotonically increasing and decreasing respectively with the increase of exchange power.Battery cost curve determines the curve trend of the total cost. When the exchange power is 0.8 times the reference value, the battery input costs and the total cost of the system at the same time to a minimum value.

In some occasions, unbalanced power is large because of the load which has a low cost-effective utilization. After abandoning this small part and directly convert it into load shedding, the battery input is reduced and the total cost is reduced as well. Besides, the unbalanced power is influenced by the exchange power between big grid and micro grid, different distribution is occurred when the exchange power is different.

The total cost is consist of storage investment, MT output and purchase cost. The extreme situation of this mode is grid-connected operation. The ideal exchange power should change all the time with the load change and there is a best solution at any time. Although setting a constant value is not the best solution, it will not influence our analysis. We can divided the straight line into different segments to fitting the ideal exchange power curve.

5.2.3 Isolated Island Operation

Isolated island is operating without power exchange with distribution grid. Micro grid supply all the load by MT, battery, WT and PV. In this case, the WT, PV, original load and EV charging load are all fixed value. The optimized items are battery investment, MT output and penalty term.

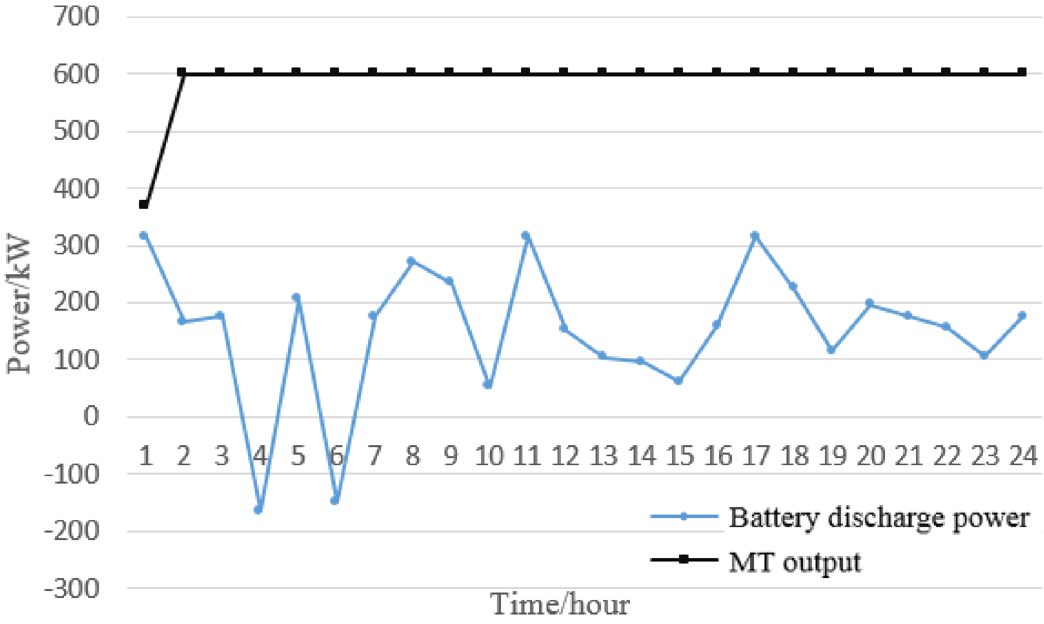

Figure 5-11 MT output and battery discharging power curve in isolated island operation

Figure 5-11 shows micro turbine and battery output in isolated island operation. When isolated island operation, the micro grid and power grid is disconnected and the voltage and frequency are supported by the micro turbine. As can be seen in the figure 5-12 that MT keeps working all the time. While, the battery keeps discharging. The lack of purchasing power from the grid, micro grid operation relies on the controllable source and storage. In this case, the battery has a larger capacity and power input, P_{smax} of 314.6kW, E_{smax} to 5519kWh.

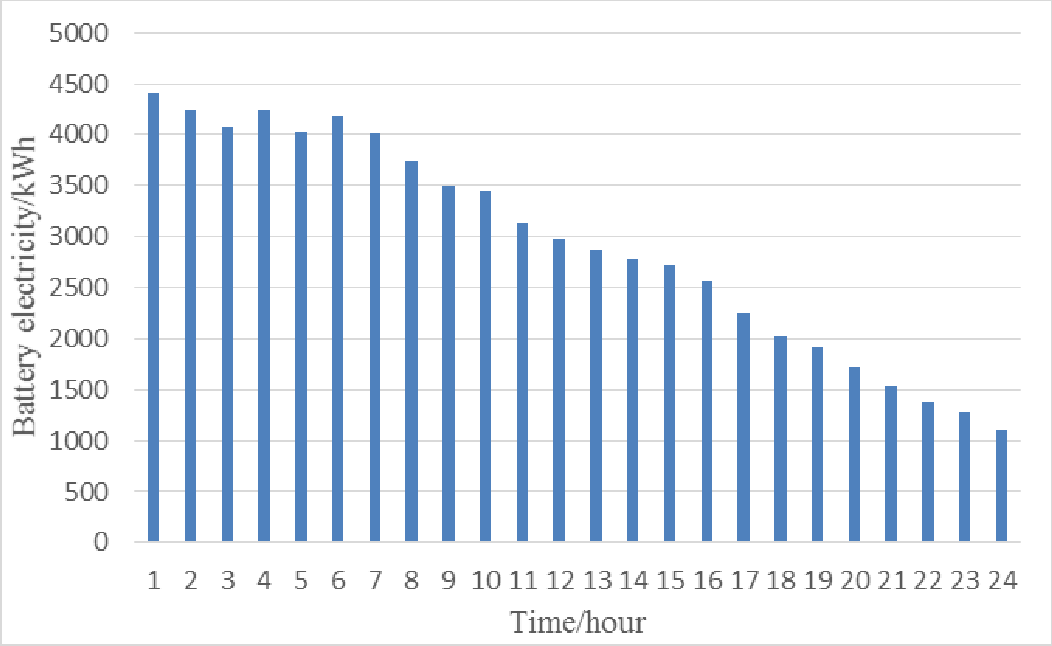

Figure 5-12 Electricity of battery in isolated island operation

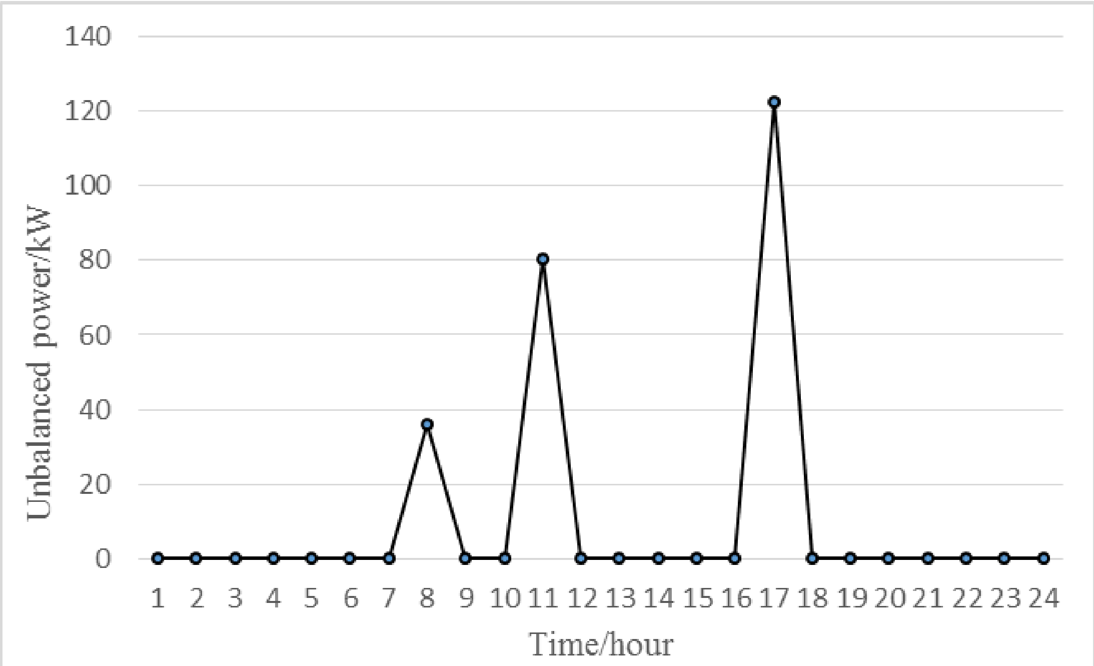

Figure 5-13 Unbalanced power curve in the case of isolated island operation

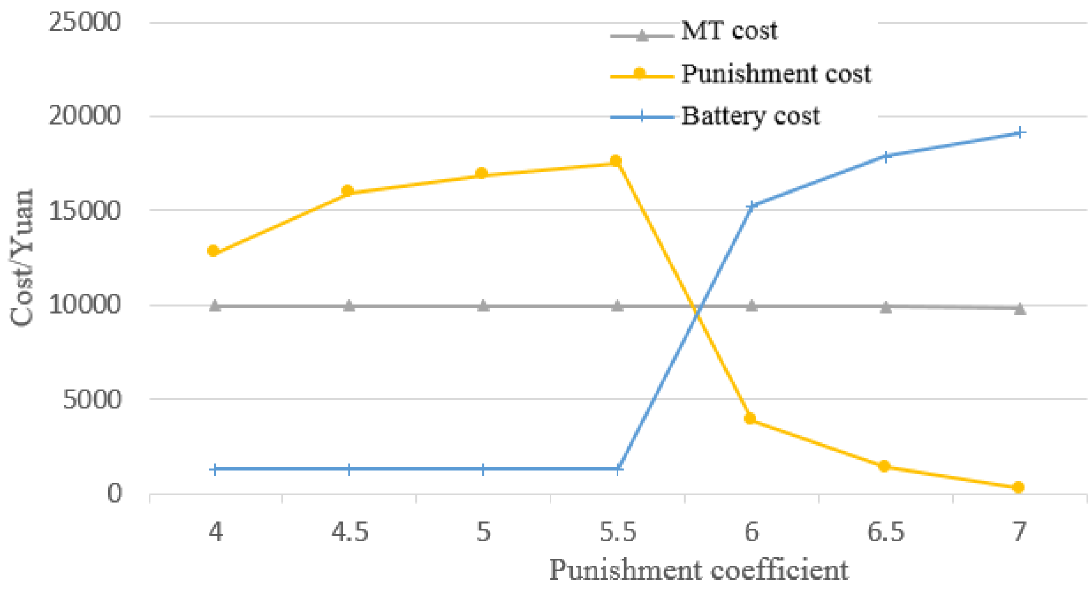

Figure 5-14 Cost of different items with the change of penalty coefficient

The imbalance mainly generated from wind or PV overflow and load shedding. This item will help improving the utilization frequency and reduce the load shedding. On the other hand, when the peak load is too large, the storage invest for it and the utilization frequency is too low, the method of putting in storage whatever the cost may not be the best solution. We can give up the excessive load, and convert it into a penalty term in order to achieve optimal operation. Figure 5-13 is the unbalanced power curves. It can be seen that in three periods of time, there exists imbalanced power, which are influenced by the size, load distribution, storage investment and so on. This part of imbalanced power make up the penalty costs.

Figure 5-14 is the cost curve changing with different penalty coefficient. Since the micro gas turbine runs as an irreplaceable role to support in the isolated island operation strategy, it is working at full force all the time. With the change of penalty coefficients, battery cost and penalized cost show the opposite trend. This is because the two variables are mutually exclusive. The more put of the battery, the less the unbalanced power is, and vice versa same. The penalty factor determines the punish term weight. When the penalty coefficient becomes larger, the system in order to achieve a minimum operating costs, will increase storage capacity and reduce the imbalance of power, which lead to the increase of the battery cost, and vice versa. As can be seen from the figure, battery cost and penalty cost varies sensitively with the penalty coefficient.

5.3 The Economic Operation of Micro Grid with EV Coordinate Charging

In the previous section, we make analysis about micro grid economic operation with EV non-fixed charging from three different operation mode in three different view of MT output, exchange power and penalty coefficient. In this section we combine related content in the third chapter of electric car charging, analyze economic co-operation with the electric car orderly charging. While the parameters do not change, with 600kW maximum output of micro turbine and 300kW exchange power limitation.

5.3.1 Two Step Optimization

Because the EV charging load is influenced by the characteristics of car owner, it can be used to smooth the generation output to achieve the load transferring. According to the analysis in chapter 3, we know that optimized dispatching can be used to smoothing the load fluctuation as well as load shifting. This segment will discuss the situation that EV undertakes the load shifting task. We will first use EV to charge coordinately to smooth the curve of load, PV, WT and so on. And then to substitute the smoothed curve into micro grid to carry out economic operation.

Step1: EV coordinately charging to smooth load containing PV and WT

$$min\,O = min\sum_{n=1}^{24}\left|P_{ln} - P_{wn} - P_{pn} + \sum_{1}^{k}P_{nk} - P_{av}\right| \tag{5.5}$$

$$P_{av} = \frac{1}{24}\sum_{N=1}^{24}(P_{ln} - P_{wn} - P_{pn}) \tag{5.5}$$

Where, P_{ln}, P_{pn}, P_{wn} stand for the load, PV output and WT output, Pnk is the charging load of electric vehicle. This segment make analysis in the coordinate charging to verify the function of EV as the transferring load. V2G, namely sending electricity back to grid is not considered here.

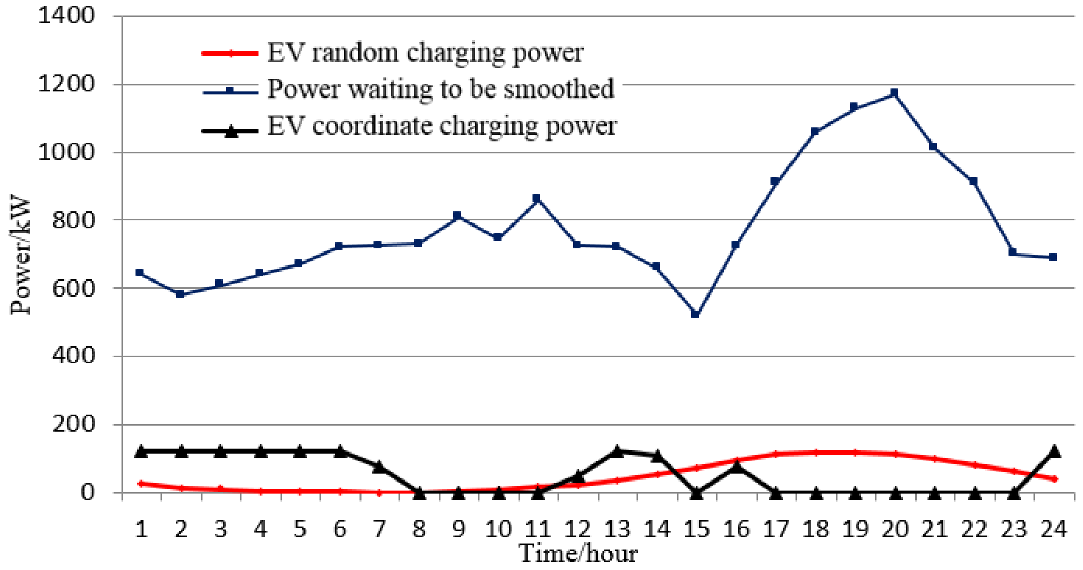

Figure 5-15 EV coordinate charging power

Figure 5-15 is the curve of charging load dispatching power and the load to be smoothed, which can be written as $P_l - P_w - P_p$. We can see that after coordinate charging, the charging load will become large in the midnight and small in the natural peak load, EV charging load becomes zero. In this way, the total load, which contains both the charging load and original load becomes small.

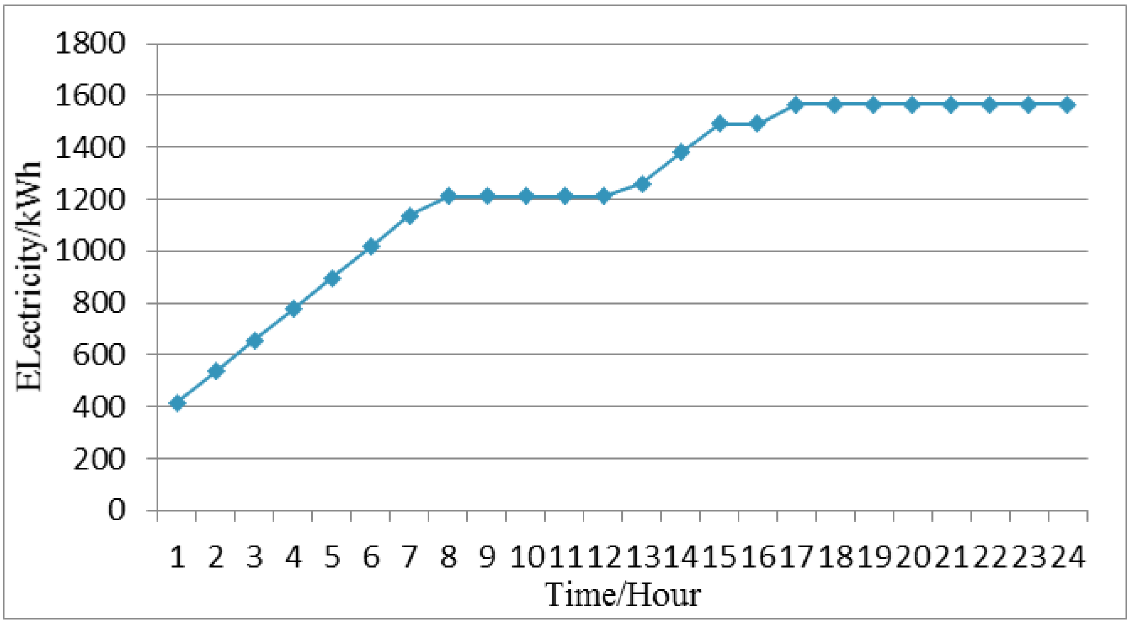

Figure 5-16 the total amount of EV charging electricity

In our model, minimize fluctuations is the objective function, while, constraints are power and energy balance. We can get electric car charging power and electricity as shown in

Figure 5-15 and Figure 5-16 in accordance with the study in chapter 3. As can be seen from the 5-15, for the charging power of the battery is concentrated in 1: 00-7: 00 and 12: 00-17: 00, which are time for sleeping and work time. So, it is suitable for the EV charging. On the other hand, these two periods are two valleys to be smoothed. Electric car batteries are charging in these periods to smooth the load curve. Figure 5-17 is the comparison of before coordinate charging of EV and after, where the effect of helping load shifting can be seen.

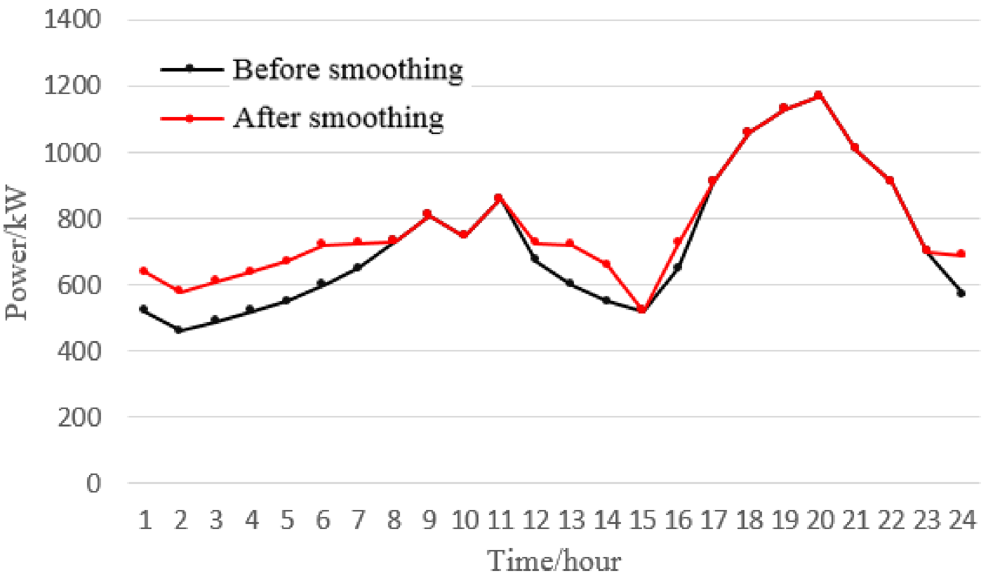

Figure 5-17 The EV transferring load before smoothing and after smoothing

Step2: Micro grid economic operation using the smoothed curve

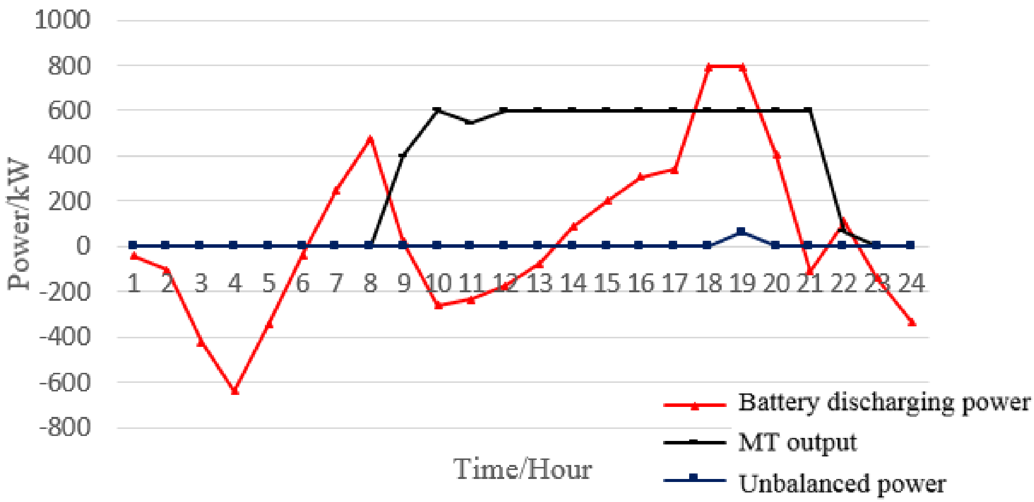

Figure 5-18 Operation curve with EV coordinate charging in isolated island mode

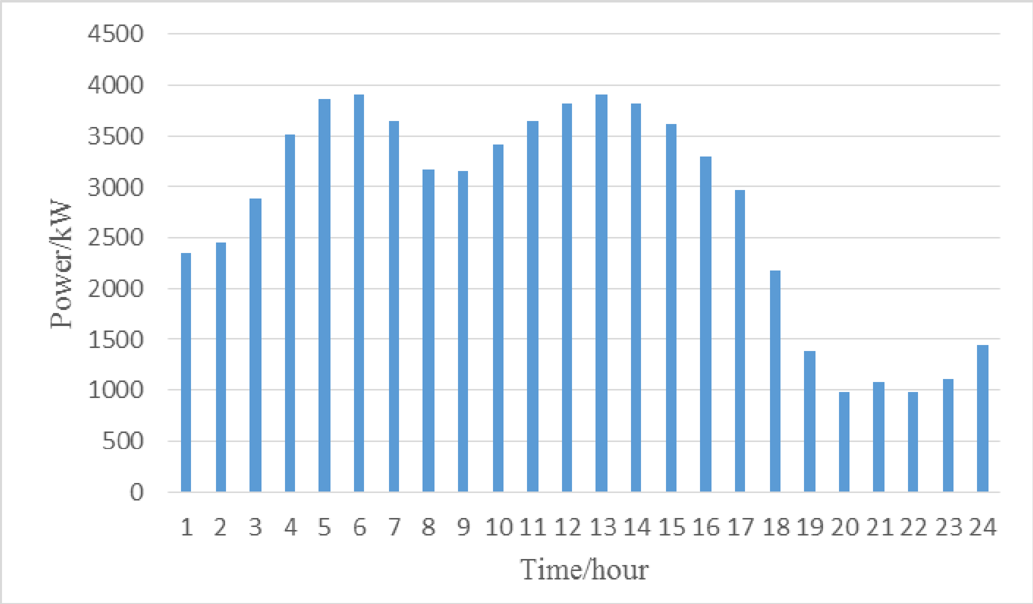

Figure 5-19 Capacity of battery with EV coordinate charging inisolated island mode

Figure 5-18 is the Operation curve with EV coordinate charging in isolated island mode. Similar to Figure 5-11, microturbines are kept in large output all the time. The battery discharges meet the maximum in the evening peak point. Consistent with the forecasting, the unbalanced power appears in the peak period. Compared with the case without electric vehicle coordinate charging, the cost is decreased.

The total cost of the system is $Cost = 18115 + 5323 + 433 + 424.41 = 24295.41 yuan$. The four parts in the equation stand for storage investment, MT cost, risk cost and EV charging cost respectively. Compared to the fees without EV coordinate charging in isolated island, $\text{Cos}\,t2 = 19129 + 9850 + 300 + 685.24 = 29964.24 yuan$, saved 5669 yuan, namely 800 euro. Storage capacity: P_{smax} is 794kW， E_{smax} is 4878kWh.

Similarly seen in grid connected operation, total cost of the whole system

$$Cost = 5018.9 + 8148.5 + 2587.1 + 424.41 = 16178.91 \text{ yuan}.$$

The four parts cost in the formula indicates to battery investment(5018.9), MT cost(8148.5), exchange power cost(2587.1) and EV charging cost(424.41). Storage investment: P_{smax} is 270kW and E_{smax} is 1316.7kWh.

5.3.2 Unified Optimization

The previous section we discussed the electric car charging by step optimization. This segment considers synthetically the transferring load and V2G technology to get the biggest profit. By putting the electric vehicle into the micro grid directly and carry on the optimization in one time. Using the grid connected operation mode for example, the objective function of micro grid operation is as follows:

$$Cost = \sum_{1}^{24} \sum_{MT} C_i(P_i(t)) + \sum_{MT} (\lambda_p) P_i(t) + \sum_{MT,WT,PV} K_{OMi} P_i(t) + C_{grid}(t) P_{line}(t) + C_{grid}(t) P_{EV}(t) + \frac{C_{ES} E_{Smax} + C_{PS} P_{Smax}}{Lifetime} \tag{5.6}$$

The formula is objective function of the unified operation mode, in which the entire cost consist of the storage investment, micro gas turbine operation and maintenance costs, purchase and sale of electricity from the grid and electric cars cost. The existence of step price provide the possibility of load shifting. Putting the index of EV cost into the objective function is used to dispatching the charging and discharging time, which has the same effect of smoothing the fluctuation.

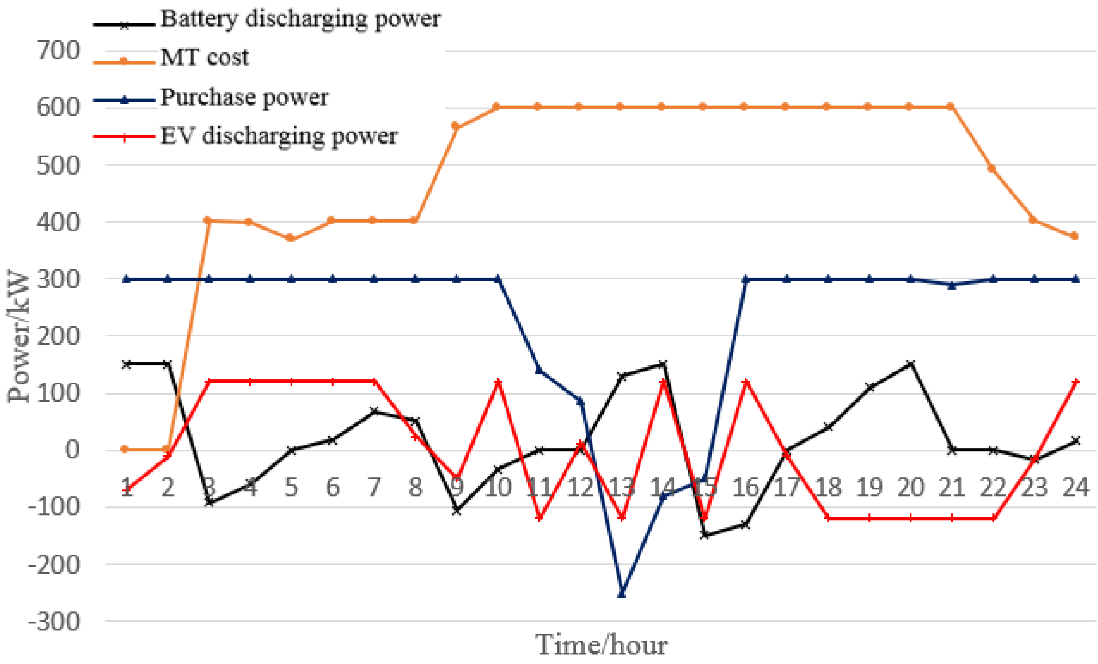

Figure 5-20 Power of different items with coordinate EV charging in the grid connected operation mode

Figure 5-20 is the power of battery, MT, exchange power and EV. Setting the exchange power limitation as 300kW. We can figure that the power of purchasing from big grid becomes smaller in the period of 11:00-15:00 and 19:00-22:00. The battery is discharging and EV is sending electricity back to the grid in these period. During all the peak load time, EV kept discharging by V2G to the grid in a high price, which achieve the target of minimize the cost.

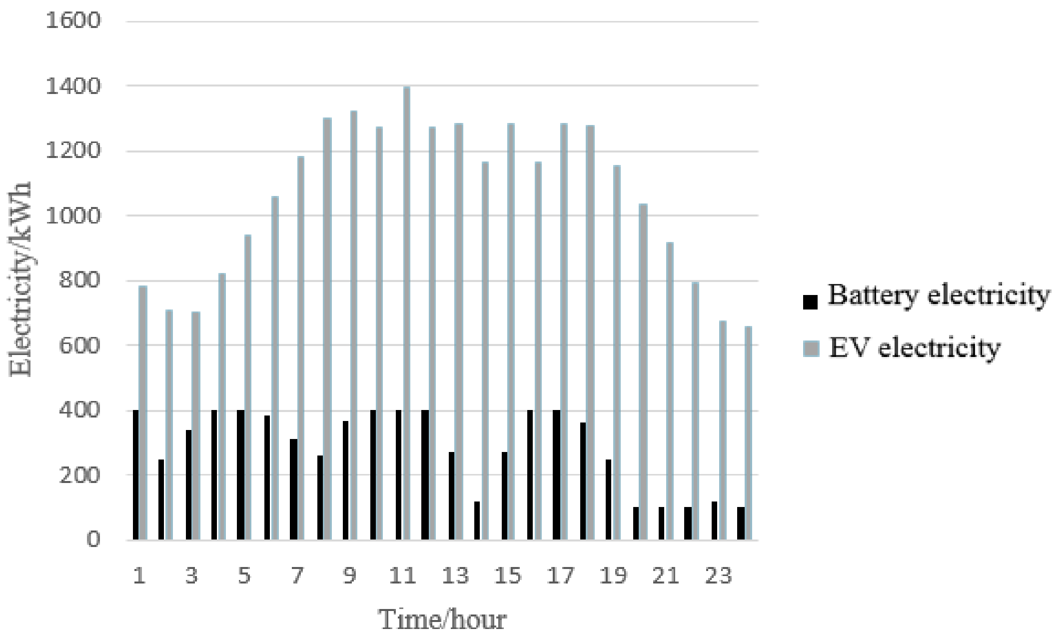

Figure 5-21 The electricity of battery and EV

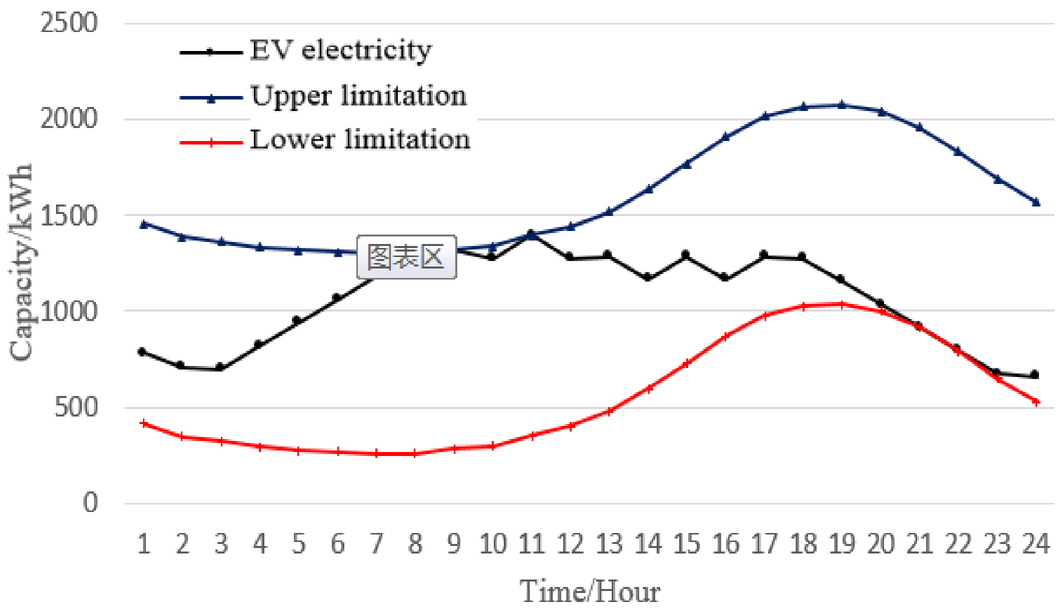

Figure 5-22 The energy electricity changing of EV

Figure 5-21 shows the capacity changing of battery and electric vehicle. It can be seen that in the situation that EV is participate in the operation to the greatest extent, the investment of storage reduce obviously. It is equivalent to the reduction of reserve capacity, which embody the convenience and economical of EV participating the operation.

Figure 5-22 shows the energy electricity changing in the whole period. The upper limitation and lower limitation are the summation of EV electricity charging and the electricity stored in the station with upper and lower battery electricity limitation. What we get is in the middle, which coordinate with our analysis.

The total cost for the system is $Cost = 2016.7 + (-612) + 7251.5 + 2194.5 = 10850.7\ \text{yuan}$, among which the storage investment is only 2016.7 yuan, dramatically less when compared with other operation mode. This is because the discharging power of electric vehicle undertake part of the function of battery. -612 Yuan is the exchanging profit, namely charging in the midnight and V2G to send back electricity in the peak time. The cost of MT and purchasing power is also less than what we calculate before. The storage investment is similar to the situation of grid connected. P_{smax} is 150kW and E_{smax} is 500kWh.

The operation of isolated island is the same as grid connected mode, we don’t talk it in detail here.

5.4 Study Case Conclusion

We have analyze the economic operation with EV non-fixed charging and coordinate charging before. In the part of EV non-fixed charging, three operation modes are discussed, including grid connected with constant exchange power, grid-connected with non-fixed charging power and isolated island charging. In the part of EV coordinate charging, step optimization and unify optimization are compared. Step optimization only consider the function of transferring load while unify optimization consider V2G as well as transferring to different time. The table below gives the exactly result of operation fees in different operation mode.

As can be seen from the table：

1) When the electric vehicle intergrated into scheduling, function as both shifting loads or V2G dispatching, the total cost of the system is generally smaller than the one as only

normal load. The situation of smallest fee is the operation of grid connected with EV acting as transferring load and V2G, 10850.7 yuan in our study case, while the largest fee is 24295.41 of isolated island operation with EV acting just as a normal load.

Table 5-4 The result of operation fees in different operation mode (unit: yuan)
(yuan, China's currency measurement unit, nearly 7 yuan equals to 1 euro)

Operation Mode		Battery cost	MT cost	Exchange Power cost	Risk cost	EV cost	Total cost	Battery	
								Capacity /kWh	Power /kW
EV without participa -ting	Constant grid connected	1714.8	3335	6910	0	685.24	12672	448	106.5
	Non-fixed grid connected	8858.2	7573.7	2507.1	/	685.24	19624	2388.7	384
	Isolated island	19129	9850	/	300	685.24	29964	5519	314.6
EV participa ting	Step optimization Grid connected	5018.9	8148.5	2587.1	/	424.41	16179	1316.7	270
	Step optimization Isolated island	18115	5323	/	433	424.41	24295	4878	794
	Unified optimization Grid connected	2016.7	7251.5	2194.5	/	-612	10850	500	150

2) When the electric vehicle charge using three different ways to integrate to the big grid: the original, load shifting, V2G power into the grid Reversely, the cost for power were 685.24 yuan, 424.41 yuan and -612 yuan respectively. EV coordinate charging will help shifting the load, reducing the storage configuration and micro turbine output, which will help optimize the curve. The mode of V2G can help the system take use of the step price to purchase in the low price and sell in the high price to make profit.

3) When the electric car is not involved in scheduling, micro grid operating costs are in the following sequence: island operation> grid connected with arbitrary exchange power> grid connected with random power. The gap is mainly reflected in the input of storage costs. When isolate island operation, because there is no external power supply, we must devote sufficient storage to meet the load demand. While in the constant power given of grid connected situation, energy storage investment decreases. While the restriction of

the upper limit specified power transmission is 300kW, it is still big when compared to the constant exchange power condition. The meaning of constant power lies in that micro grid is seen as a single controllable elements to control its transmission power, what we did is just start with a qualitative analysis. The ideal exchange power curve can be simulated if method is improved.

4) In the case of electric vehicles involved in optimization scheduling, step optimization of isolated island is greater than the cost of grid connected step optimization, which is still because the islands operation need to invest more battery storage. The fees is nearly doubled. In the situation unify grid connected, the storage investment cost dropped to 2016.7 yuan, nearly half of grid connected operation, which is the smallest of all the situation.

5) The penalized fee is relatively small, 300 yuan and 433 yuan, which is at the cost of load shedding and PV, WT overflow. For this part of the low efficiency and cost-effectiveness loads, we would like to give it up and converted to a certain costs. The penalty term in the table is small, and consistent with the actual situation, which supply a reasonable explanation of the data.

6) Whether or not the electric vehicle involved in scheduling, in isolated island operation, the battery capacity and power input are pretty large, respectively 5519kWh and 4878kWh. This is because there is no external power to support, in the circumstance of MT fixed upper limitation, we had to put more storage to increase the output power, in line with the actual situation.

6 CONCLUSION AND PROSPECTS

6.1 Conclusions

Energy problem, environment problem or the reliability of power supply problems, in the current social structure, it is economic problems and are measured by economics. As a new network technology combined with new energy, distributed generation, energy storage technology, micro grid have enough reasons to get sufficient attention. Electric cars achieve more prominent significance and its enormous potential can be foreseen. To measure in the view of economic operation scheduling containing electric vehicle storage station as well as distributed generation has social significance and economic values. This thesis firstly describles the concept and background. Then, different distributed generations are analyzed. After that, chapter 3 analyzes the characteristics of electric vehicle and build the model for EV with the charging expectation estimated from the data of American transportation department. The models of individual elements in the micro grid and economic model of the whole system are built. On the basis of all the models, chapter 4 analyzes the system in the optimized operation point of view with the objective of minimizing total cost, which includes storage investment, operation fees and penalty cost. At last, chapter 5 gives out a study case of micro grid containing wind turbine, photovoltaic, battery, and electric vehicle storage station. By programming in CPLEX using the model built before, this part provides the result of three different operation mode of isolated island, grid-connected with constant exchange power and grid-connected with non-fixed value. After making comparison with the result of different operation mode, we get the conclusion which is correspond with the analysis. Details are described below:

1）Built the micro grid model, researched on the control method and verified in simulation software.

2）The basic framework for micro grid energy management system were studied, including distributed power output and load forecasting. Select and apply PV, WT, MT and battery within the micro grid system which are relatively mature for analysis. Studied the output characteristics, electricity generating principle, operating characteristics, the relationship between operating parameters and economy. Established economic models for these micro grid units according to the output cost curve.

3）This thesis also presented research on the characteristics of electric vehicle. By analysis the data of American transportation department, the demand expectation of the owner in 24 hours was achieved. Making use of the charging expectation, we built the mathematic model for the electric vehicle storage station, which provides possibility for electric vehicle to coordinate charging to optimize the load curve.

4）Chapter 3 calculated the lifetime of the battery using the rainflow algorithm programmed in MATLAB. In this way, the lifetime of battery in the normal operating state can be esimated. Took Tesla electric vehicle for example to calculate the one time storage investment and convert it into the cost for one day.

5）Built the economic operation model of micro grid containing the electric vehicle storage system. Analysized from three operating mode, isolated island, grid-connected mode with constant exchange power and grid-connected mode with non-fixed exchange power. Built the objective function and constraints in different modes and strategies. Considering that the storage has a big influence on the operation of micro grid, the investment of battery after convertion into daily cost was listed in the objective function. In isolated island mode, considering the cost of unbalanced power which is represented by load shedding and WT or PV overflow (waste). In order to measure this, an item called penalty cost was brought in to give up the small part of load which is low utilization and low perfermance price ratio in the point of view of economic.

6）Divided the way electric vehicle integrating in the micro grid operation in three different degrees: as normal load, as transferring load and V2G sending back electricity. In the calculation, using the normal optimization, step optimization and unify optimization three ways to construct the model. In the step optimization, we firstly use the electric vehicle to smooth the output power of renewable energy and the load. Then put the curve optimized in the micro grid to get the best solution. Unified optimization was to put the electric vehicle into the micro grid directly and solve it together with other distribution generation.

7）Took an industrial district for example, set the related parameters, program in CPLEX and simulate in different operation and sloved the best solution. After comparison and analysis with different results, the thesis get the conclusion: the output of distributed generation in micro grid is related to the price. There is larger demand of storage in isolated island operation, while the risk cost and the total cost is relatively large. The V2G mode of electric vehicle is a good way to reduce the cost pressure of storage configuration, as well as making profit, which support and verify the theoretically analysis.

6.2 Prospects

In this thesis, we did some work in micro grid systems with electric vehicle modeling and simulation, analyzed and explored the micro grid optimization and part of energy management. But the model is not perfect, there are still many deficiencies, which should be further improved in the following points :

1) The function of battery in shifting peak load, reducing the reserved capacity aspects are not well represented. Since in the present model, controlled distributed power is single, just micro turbines, more storage had to be used to meet the load demand.
2) The model of electric vehicle is considered as a single constraint of power and energy. For the charging process internal the station is not carefully explored. There is also not a detailed explanation about the belonging of electric vehicle cost. The business mode between the operators and electric vehicle should be further explored.
3) From the economic point of view introducing penalty term to replace the portion of lower utilization load need to be perfected in the practical application. The next step can add another index of importance as a dual indicator to evaluate. Meanwhile, the impact of the electric vehicle connected into grid can also be considered to improve risk mechanism

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